SITE FORMATION PROCESSES AND ENVIRONMENTAL RECONSTRUCTION AT THE MINK ISLAND ARCHAEOLOGICAL SITE (XMK-030), KATMAI NATIONAL PARK AND PRESERVE, ALASKA.

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A

DISSERTATION

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By

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Abstract

This research was initiated to document climate and weather, as reflected in geoarchaeological data, and identify, if possible, any related changes in human behaviors at the Mink Island Site (XMK-030) on the Shelikof Strait, in Katmai National Park, Alaska. The goal was to identify local environmental changes through the analysis of sediment micromorphology, grain-size, and scanning electron microscopic (SEM) observation of sediment grain surface textures, and use the data to determine if local environmental changes were related to periods of human occupation, or associated with local or regional hiatuses.

Research indicated that micromorphology, grain-size and SEM analyses are not the most appropriate analytical techniques to develop proxy climate data. This is not to say they are not applicable to archaeological analyses in general, or even in the GOA. They are however, ineffectual means by which to obtain data regarding *specific* environmental events, and cannot therefore, be used to extrapolate environmental drivers of human behavior. However, both micromorphology and grain size analysis are appropriate techniques to address the proposed research questions and both indicate that the two primary non-cultural formation processes on the site were aeolian and colluvial deposition.

Analyses suggested that there were not widely divergent depositional regimes. Sediments within the site were likely deposited by aeolian and/or colluvial movement with secondary deposition during freezing temperatures likely during periods of winter

abandonment. During occupation periods, sediments were likely derived from these same processes as well as material brought into the site by human occupants.

The differences between abandonment and occupation levels are very distinct; humans clearly affected the means by which material accumulated in site deposits. Analysis suggests winter abandonment but beyond that, it is difficult to extrapolate additional seasonality data.

Methods used for analysis of the Mink Island sediments were unable to provide specific information regarding environmental events at the site or within the broader GOA. However, analyses did provide an additional tool to identify the season of site abandonment. The data presented here also indicated the depositional processes that acted on the site, and allowed the identification of post-depositional processes that altered sediments after human abandonment.

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Chapter 1

Introduction

1.1 Introduction

Archaeological deposits are not static. Cyclical and non-cyclical perturbations in climate and environment generate change in the processes acting on site deposits and can affect sediment structure and composition. Researchers must be aware of how changes in the past have influenced deposits examined in the present. Examination of sediment structure provides a means by which to identify these processes and to derive information about past climatic and environmental conditions. This research is designed to document climate and weather, as reflected in geoarchaeological data, and identify, if possible, any related changes in human behaviors at the Mink Island Site (XMK-030) on the Shelikof Strait, in Katmai National Park, Alaska. The goal is to identify local environmental changes through the analysis of sediment micromorphology, grain-size, and scanning electron microscopic observation of sediment grain surface textures. These data are compared to proxy climate and archaeological data compiled. Fluctuations in local environment as revealed through archaeology may be reflected in the larger regional context of the Gulf of Alaska (GOA), and in the cultural record of the Mink Island (XMK-030), and other archaeological sites in the Gulf.

1.2 Background

The Mink Island site (XMK-030) sits on a small unnamed island in the Shelikof Strait between the coasts of Katmai National Park, on the Alaska Peninsula, and Kodiak

Island. It is situated on the northwest corner of the island on a bedrock platform that is bounded to the east by a tombolo or spit of land that attaches the site to Mink Island proper (Hilton 2002). To the west, the base of the site is bounded by another tombolo that connects Mink Island and Little Takli Island during low tide.

Initial human occupation dates between 4180 ± 40 B.P. and 6300± 50 B.P (Schaaf 2002). These early occupation strata are capped by a 1.5-meter (m) layer of sand separating them from the upper deposits that date between 400 and 2000 years B.P. (Hilton 2002). The total period of human occupation is roughly 4000 years.

National Park personnel excavated Mink Island during summer field seasons between 1997 and 2000. Excavation followed both five centimeter (cm) arbitrary levels and natural levels as determined by sediment consistency, color and the presence of anthropogenic features. Upper level midden excavations were primarily supervised by Mike Hilton of the National Park Service, while excavation of the lower midden was supervised by Jeanne Schaaf.

During the 2000 field season samples for micromorphological analysis of the lower midden were collected as were the majority of the sediment samples for grain size and scanning electron analyses. Some samples from the 1998 and 1999 field seasons, stored at Park Service offices in Anchorage, are also utilized for grain size analysis.

1.3 Background Continued and Research Questions

Analytical methods derived from the field of geology, namely micromorphological, grain size, and scanning electron analyses of sediments are used to identify natural, nonanthropogenic, processes responsible for site formation, and to make inferences about past local climate and environmental conditions. Use of these techniques allows research questions to be addressed. These are:

1. Are there structural changes in the deposit, and if so, what do they look like?

2. Do these structural changes indicate changes in depositional regimes throughout time, or was sediment deposition during abandonment governed by one process?

3. Do the periods of site abandonment correlate with changes in depositional regimes and if so, do these changes indicate seasonal changes or do abandonment episodes correlate to larger regional environmental fluctuations?

4. Do site deposits suggest changes in sea level throughout time, and the site's position relative to the shoreline? If so, are these reflected in the larger Gulf of Alaska?

Microscopic sediment features, such as deposit structure, mineralogical composition, chemical alteration and grain features provide insight into the depositional mechanisms and post depositional processes that are associated with different climatic conditions. The surficial characteristics of sediment grains are indicative of a variety of depositional processes, including aeolian and glacial deposition and subaqueous deposition (Krinsley and Doornkamp 1973; Mahaney and Kalm 2000; Smart and Tovey 1981; Whalley and Krinsley 1974).

Sediment grain size also provides information about depositional and erosional processes both cultural and natural and contributes paleoenvironmental data useful in the reconstruction of past local climate conditions. The identification of sediment regime changes allows documentation of changes in water energy. High-energy environments are associated with larger sized particles, while calmer, low energy environments are associated with smaller, finer grained particles. Similarly, site placement relative to the shoreline is indicated by grain size distribution as coarse-grained particles, cobbles, pebbles and fine sand indicate a beach setting, while smaller grained materials are associated with offshore/littoral environments. The ability to place the site relative to the shoreline assists interpretation of relative sea-level change throughout the site's history (Bagnold and Barndorff-Nielsen 1980; Baize 1993:34; Fieller et al. 1992; Gilbertson et al. 2004; Hartmann and Christiansen 1992; Knight et al. 2002; Sutherland and Lee 1994).

Grain size data are used in an attempt to identify depositional regimes, and the site's position relative to the shoreline throughout time storm surges and possibly storm frequency. Grain size data may be used to identify storm deposits. Storm deposits are typically composed of sea sand and are found periodically in coastal sediment deposits. Storm surge frequencies and storm periodicity are seasonal indicators as storms are more frequent and more severe in the winter months. Delineation of storm activity (see Mason and Jordan 1993 for a similar study along the north Alaska coast), enables the examination of the influence of these periods on the human occupants at Mink Island. In the Gulf of Alaska, the archaeological record documents several modifications in human settlement and subsistence patterns possibly related to changes in environmental conditions such as sea-level shifts, earthquakes, glacial re-advances and increased storm frequencies (Crowell and Mann 1998; Jordan and Maschner 2000; Mann et al. 1998; Mason and Jordan 1993). Although sea-level changes and earthquakes likely altered the landscape of Mink Island and resulted in some changes in the lives of its prehistoric peoples, it is periods of storminess that are of particular interest as they may have influenced site use or abandonment. Such conditions may limit people's ability to navigate coastal waters, thus affecting travel and hunting. Furthermore, modern research documents that increased periods of storminess affect seal and sea lion populations by affecting pup survival rates (DeLong and Antonelis 1993; LeBoeuf and Crocker 2005).

Storm patterns identified in the archaeological record at Mink Island will be placed in a regional context in an attempt to correlate them with broader patterns documented by proxy climate indicators from the GOA. Of particular interest are possible correlations between increased periods of storminess in the GOA and El Niño events. Although El Niño is primarily associated with southern portion of the Pacific Ocean and the alteration of weather patterns, trade winds, and ocean currents there, more northerly areas of the Pacific coast are also affected (DeLong and Antonelis 1993; Duffy and Bryant 1998; Weingartner et al. 2002). El Niño events change ocean current patterns and result in increased storm frequency and alteration of the habitats of aquatic resources. Species are affected not only by changes in storm patterns, but also by the shift in aquatic resources that subsequently cause perturbations throughout the entire food chain.

The results of this research have important implications for archaeology. I illustrate that micromorphology and grain size analysis allows insight into site seasonality, information that may not be readily discovered at every site. By extrapolating this seasonal evidence, we also get hints of possible subsistence practices along the Pacific coast of the Alaska Peninsula. I also provide information relevant to sea level models for the GOA, illustrating the validity of the model developed by Crowell and Mann (1998; Mann and Crowell 1996).

1.4 Thesis Structure

To familiarize the reader with the concepts, environment and cultural setting in which this study is situated, the chapters are laid out progressively. Chapter 2 provides a basic outline of present and past climate conditions in Katmai National Park and the surrounding region and at the Mink Island site (XMK-030), while Chapter 3 provides a brief discussion of the archaeological cultures along the Alaska Peninsula, Kodiak Island and Cook Inlet. If one word were used to describe the archaeological cultural history of the northern Alaska Peninsula and adjacent Kodiak Island, it would be confusing. Each river drainage, archipelago, and shoreline is assigned its own cultural chronology with phases from each locality overlapping those of others, both temporally and stylistically. The development of relationships among prehistoric peoples in the area is little understood with some areas such as the Naknek River drainage and Kodiak Island the subject of more research than others, like the Shelikof Strait.

Chapter 4 describes the analytical techniques and results of micromorphological analysis of Mink Island site (XMK-030) sediments. A brief history of methods in geology and archaeology is provided and definitions and terms defined. Chapter 5 describes techniques used for and the results of grain-size and scanning electron analyses of sediment samples. In Chapter 6, the research questions proposed and a comparison of findings with data compiled from the broader Gulf of Alaska regions, as well as environmental fluctuations and their possible impacts on prehistoric peoples throughout the GOA are considered.

Chapter 2

Past and Present Environmental and Ecological Conditions on the Alaska Peninsula and Western Gulf of Alaska

2.1 Introduction

The Mink Island site is located just off the south coast of the northern Alaska Peninsula, within the Katmai National Park and Preserve (Figure 2.1). The Alaska Peninsula projects for 800 km from southwestern Alaska, southwest to the Aleutian Island arc. The eastern and western sides of the Peninsula are divided by the Aleutian Range which is composed of volcanically active peaks that rand from 900 to 3000 m above mean sea level (amsl). The Pacific side of the Alaska Peninsula is characterized by a convoluted coastline of rugged cliffs comprised of rounded, folded and faulted sedimentary ridges that jut into the Shelikof Strait and sand and gravel beaches in the smaller, protected harbors and inlets. The northern shores of the Peninsula are part of the Bristol Bay Coastal Plain and are overlain by wet tundra and glacial outwash.

2.2 Bedrock Geology

Kodiak Island is comprised of marine sedimentary rocks deposited by underwater landslides which are created by deformation of flysch rocks and melange rocks, which are derived from materials scraped off the upper crust of the Pacific Plate as it subducts

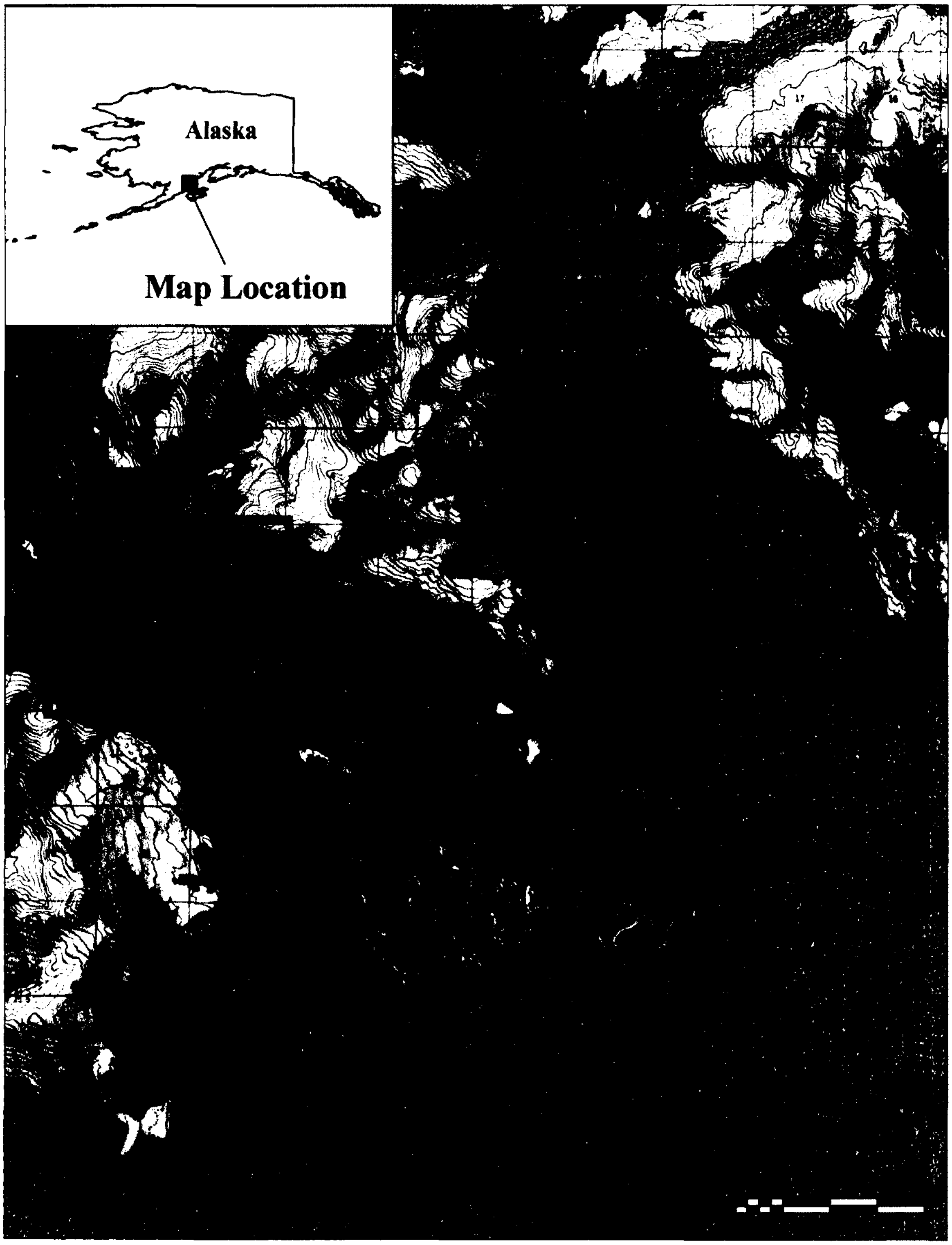


Figure 2.1 Location of the Mink Island Site as depicted on USGS 7.5' topographic map, Katmai Quad A:3.

beneath the North American Plate (Mann and Crowell 1998:4). The underlying bedrock of the Alaska Peninsula is the Alaska Peninsula terrane, which is divided into two subterranes, Iliamna and Chignik. Iliamna is composed of several different lithological types: deformed marine sedimentary and volcanic rocks dating from the Mesozoic; schists, gneiss, and marble from the Paleozoic and Mesozoic; and plutonic rocks from the Alaska-Aleutian Range batholith. The Chignik subterrane, which underlies Katmai, is comprised of deformed shallow marine and continental clastic sedimentary rocks, and deep-marine, volcanic and calcareous rocks (Wilson et al. 1999:4-6).

The Chignik subterrane is further subdivided into the Naknek and the Shelikof Formations. The Naknek formation is made up of materials deposed during the Jurassic including arkosic sandstone, conglomerate and siltstones. All are indicative of a shallow-water, nonmarine depositional environment, as are the Cretaceous aged deposits in the formation, which consists of calc-arenaceous sandstones, fine-grained siltstone, and shale (Wilson et al. 1999:7).

The Shelikof Formation has lower sections comprised of greywacke, conglomerates and siltstone, and upper deposits of volcanic sandstones interbedded with siltstone, and calcareous sandstone, all of which developed in a deep- to shallow-water depositional environment (Wilson et al. 1999:32).

The coast of the Shelikof Strait is structurally characterized by deformed clastic material dating from the Mesozoic and non-marine Tertiary deposits (Kelly and Denman 1992). The Strait itself is a trough running 200 km from the mouth of the Cook Inlet to just beyond Kodiak Island and spanning a width of 50 km, with a depth of over 1,100 m

(Hampton et al. 1989:96). The floor of the trough is smooth, unlike the rest of the Gulf of Alaska, and has a complex, seismically influenced, Pleistocene aged stratigraphy overlain by glacial marine deposits. These in turn underlie the uppermost marine sediment deposits that originate from the mouth of the Cook Inlet, and are laid down in the course of modern ocean circulation (Hampton et al. 1989:128).

2.3 Tectonics and Volcanoes

Tectonic activity in the Gulf of Alaska results from the convergence of the oceanic Pacific Plate and the continental North American Plate into the Aleutian Trench. The boundaries between these two plates make southern Alaska one of the most tectonically active areas in the world, capable of the largest earthquakes. The configuration of the Gulf results from this movement as well as the numerous volcanoes that dot the landscape. The Queen Charlotte-Alaska Aleutian seismic zone runs from the Fox Islands in the Aleutians, through the Gulf of Alaska southward, running parallel to British Columbia (see Figure 2.2). This area contains the Queen Charlotte-Fairweather fault along British Columbia and southeast Alaska, and the Aleutian Trench which is parallel to the Alaska Peninsula. The Queen Charlotte-Fairweather fault line is where the Pacific Plate moves northward and right laterally to the North American Plate. The Aleutian Trench is where the Pacific Plate subducts beneath the North American Plate at a rate of about 7 cm^{-1} a year (Crowell and Mann 1996:18; Jacob 1989; Jordan 2001:510; Jordan and Maschner 2000:3; Mann 1998).

The earthquakes that plague this region are created by the convergence of these two plates. As the Pacific moves northward along the Fairweather-Queen Charlotte

Fault, the two plates slide past each other, the rock is deformed and as the movement is not smooth, the two plates 'stick' together. When enough strain builds, the pressure is

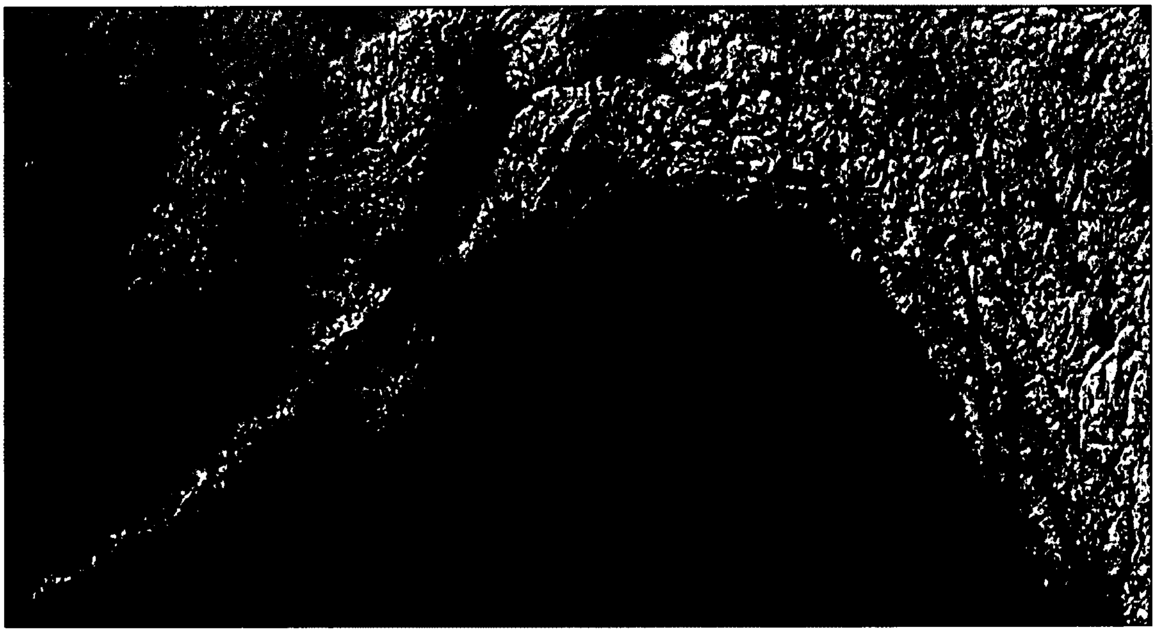


Figure 2.2 Fault system in the Gulf of Alaska and along the coast of British Columbia, Canada. Adapted from Page et al. 1991.

released with the 'stuck' portions breaking, the two plates sliding past each other, moving the earth, creating a quake (Mason et al. 1997:37). Earthquakes associated with this release occur at variable depths along the Peninsula except for the Shumagin Islands where there is a seismic gap. Here there have been no large earthquakes, nor a "plate boundary rupture since 1917" (Detterman 1986:156; Jordan 2001:511).

Beyond the earthquakes, the subduction of the Pacific Plate beneath the North American Plate has created numerous volcanoes along the Peninsula and in the Aleutian Islands (Jacob 1989:174-176; Mason et al. 1997:42). In total there are 75 volcanic centers along the Aleutian volcanic arc, 40 of which have produced more than 265 documented eruptions within historic times (Miller et al. 1998; Power 2007).

As subduction occurs, the plate plunges into the earth where pressure and heat melt the crust generating magma or lava. Because magma is less dense than the surrounding rocks, it rises towards the earth's surface through faults and fractures created by plate movement. When the magma breaches the surface, various types of volcanoes are formed. Stratovolcanoes or composite volcanoes comprise most of those found in Alaska. Stratovolcanoes or composite volcanoes have an outer conical structure resulting from the build of up slow moving lava, as well as pyroclastic ejecta (solid rock material, ash, and cinders emitted from the volcano) around the volcanic vent. Frequently, composite volcanoes produce highly explosive eruptions. If the eruption is strong enough, the upper cone portion of the volcano can collapse in on itself and create a caldera. In total, there are at 49 volcanic centers on the Peninsula 20 of which have been active historically, and 13 during the Holocene. Of the 49 located on the Peninsula nine of them (Douglas, Katmai, Novarupta, Trident, Martin, Mageik, Ukinrek, Peulik, and Chiginagak) are within one hundred kilometers of Mink Island.

Throughout the Holocene the Alaska Peninsula has experienced periods of considerable volcanic activity, the first between 8000 and 9000 B.P., with the notable eruption of Aniakchak between 5030 and 5300 B.P. (Addison et al. 2010:278) and the second between 3400 and 4000 B.P. (Dumond and Knecht 2001; Mason 2001; VanderHoek 2009; VanderHoek and Myron 2004). During the second eruptive period Mt. Hayes, Mt. Redoubt, Mt. Dana, Mt. Illiamna erupted and possibly Mt. Illiamna, Kaguyak, Veniaminof, and Aniakchak (Riehle et al 1998; Schiff et al. 2010; Waythomas et al. 2000;VanderHoek 2009:196). During this time four caldera-forming eruptions occurred on the peninsula and four more volcanoes had significant eruptions (Riehle et al. 1998; VanderHoek 2009).

The ever present tectonic activity and occasional volcanic eruptions pose considerable hazards for people living along the Gulf coast. While there is the danger of landslide, and uplift and subsidence of the land, the primary cause of earthquake associated deaths, are tsunamis or tidal waves (Davis 1971; Mason et al. 1997:182). Tsunamis are generated by vertical or horizontal movement of the sea floor, or by large submarine landslides. The sudden movement of sediments or ocean floor displaces the ocean water, generating a tidal wave that radiates outward. Landslides are also associated with earthquakes as sediments become unstable when shaken, resulting in liquification of sediments and slope failure (Crowell and Mann 1998:16; Jacob 1989:173; Mason et al. 1997:45).

2.4 Tectonics and Sea Level Change

Tectonics events have always played a role in peoples' lives in the Gulf of Alaska. Large earthquakes here cause coastal subsidence, where the shoreline drops into the sea, or uplift, where it rises up. One of the largest earthquakes ever recorded was on March 27, 1964. With the seaward movement of the Pacific plate, the earthquake measured 8.4-8.5 on the Richter scale and 9.2 on the moment-magnitude scale, affecting the continental shelf between Cape St. Elias and Kodiak Island, an area of 950 km by 250 km (Crowell and Mann 1998:14). Large areas of shoreline in Prince William Sound, the Kenai Peninsula and the Kodiak archipelago were affected, with horizontal displacements of up to 30 m, coseismic uplift up to 11.5 m and subsidence up to 2.5 m (Crowell and Mann 1998:14; Mann 1998:18).

The quake was caused by the accumulation of stress between the North American and Pacific Plates between 1200 B.P., the time of the last major quake in this region, and 1964. In a subduction zone, like the Aleutian Trench, the upper plate is deformed elastically and is compressed and carried downward, also causing downwarping over time, as the lower plate plunges into the mantle. Eventually the stress that has accumulated in the area of downwarping is released creating an earthquake and, in this case, causing subsidence, uplift and horizontal movement along fault lines (Crowell and Mann 1998:15; Davis 1971; Mason et al. 1997:182).

Although tectonic movements frequently affect the people living in southwest Alaska, only three studies have examined how earthquakes and resulting sea level changes affected prehistoric peoples and archaeological sites (see Crowell and Mann 1998; Jordan and Maschner 2000; Mann and Crowell 1996), although several geologists have examined shoreline displacement associated with tectonic activity throughout the Gulf of Alaska and Cook Inlet (see Combellick 1990, 1991; Combellick and Reger 1994). Both geological and archaeological studies document coeseismic subsisdence every 780 to 590years and six to eight large magnitude earthquakes every 4700 years prior to the 1964 earthquake.

Crowell and Mann (1998; Mann and Crowell 1996) believe this coastal subsidence truncated the archaeological record in Kenai National Park, submerging sites on coastal spits and beaches older than 800 years with reoccupation not occurring until around 600 B.P. (Crowell and Mann 1996; Mann et al. 1998).

Evidence of subsidence events affecting human populations is also found in the Aleutians (Jordan and Maschner 2000) in till and lacustrine deposits at Morzhovoi Bay. Deposits indicate a coseismic uplift caused by a large earthquake dating before 2150 years B.P., resulting in an instantaneous rise in sea level that moved intertidal zones landward, flooding the lower reaches of streams and estuaries, and truncating sites older than 2200 years. There was extensive alteration of the coastline along the Peninsula and in the Aleutians and this possibly caused what appears to be the three hundred year cultural hiatus between 2100 to 2400cal years B.P. and a subsequent alteration in observed settlement and subsistence patterns (Jordan and Maschner 2000).

Crowell and Mann (1996) developed a model of sea level change for the Katmai shoreline by examining the elevation of archaeological sites in Amalik and Kukak Bay, along Cape Douglas, and Kinak Bay, and by radiocarbon dating terrestrial peat bogs located in the intertidal zones of Amalik and Kinak Bays, and sampling sites on raised storm beaches in Kukak Bay. Their data suggest that relative sea level was around 1.25 meters lower than present 10,000 years ago, after which sea levels rose until about 7000 years ago (Crowell and Mann 1996:26). After 7000 years sea levels began to decline and become stable after 4000 years ago until about 200 or 300 years ago when they began to rise again (Crowell and Mann 1996:26). Sites older than 7000 years ago were probably destroyed by the most recent rise in sea level (Crowell and Mann 1996:26).

2.5 Geomorphic Development of Mink Island

The base of Mink Island is comprised of Tertiary age volcanic rocks (Wilson et al. 1999) over which soils, sediments and cultural materials were deposited over the last 6300 years. The site deposits are up to six meters deep and are composed primarily of cultural material, with approximately one and a half meters of sand the dividing the Lower Midden and the Upper Midden deposits (Hilton 2002:125). Prior to deposition of cultural materials, the northern portion of the landform on which the site is located was approximately one meter higher in elevation than the site area. As successive human occupations occurred, deposition of sediment and cultural materials produced a heightened landform, reversing the original north-south trending slope, to a south-north trending one (Hilton 2002:125).

In conjunction with human refuse deposition, sediment delivery to the Island likely came from a variety of different sources. Glacial, glacial-marine, and glacial-fluvial sediments were, and continue to be, deposited throughout the Gulf of Alaska in areas of glacial ice advancement (Hampton et al. 1986). The Coastal and St. Elias Mountains northeast of the Shelikof Strait are sources of high sediment output in the world (Jaeger and Hallet 2005).

The Bering and Malaspina Glaciers at the head of Cook Inlet also provide sediment inputs in the northeastern Gulf of Alaska, via the Copper, Alsek, Knik, Matanuska, and Susitna Rivers. As they enter the Inlet, the ocean currents carry the sediment to the west, depositing part of the sediment load in Prince William Sound and

Shelikof Strait (Hampton et al. 1986), where the finer river sediments are transported as a sorted blanket of sediment (Hampton et al 1986).

The Crowell and Mann model (1996) is difficult to apply to the Mink Island site. The oldest available date for the lowest levels of the site is 6300 B.P., making it one of the oldest dated sites on the Peninsula. If Crowell and Mann's (1996) sea level history is applied, the original occupation would have been underwater. Hilton (2002:40) suggests the island was uplifted enough to compensate for high sea levels and has experienced an amount of subsidence over the last 7000 years, as the site is currently only two meters from the shore (Hilton 2002:40). This subsidence has exposed the shoreline to erosion (Hilton 2002:40). However, if subsidence kept pace with the drop in sea level, subsequent occupations were likely at the same distance from the shore as the initial occupation. This scenario is unlikely as the initial occupation would have been inundated, and possibly obliterated and it is not. It is more likely that the subsequent occupations were located further from the active shore line as sea levels dropped.

The current rate of site erosion is a result of the sudden rise in the relative sea level over the last 300 years (Crowell and Mann 1998), along with continued submergence due to post-glacial subsidence. This has brought the site within reach of modern storm waves and is the likely reason as to why few sites dating to 5000 B.P. or earlier are found in this area of the GOA. Mink Island was likely established well above the sea level at the time of its first occupation, situated high above the storm wave maximum for higher water levels and this enabled the site to survive. The erosion is a relatively recent phenomenon and sites of this antiquity probably were more numerous along the Katmai coast but have now been destroyed by the rise in sea level. A considerable amount of survey took place along the Katmai coast after the 1989 Exxon Valdez wreckage (Dekin et al. 1993; Haggarty et al. 1991), although survey bias cannot be ruled out.

2.6 Environmental History of the Alaska Peninsula

Several episodes of climate change throughout the Holocene likely affected the behavior of prehistoric peoples in Alaska, namely the end of the Pleistocene; the beginning of the Hypsithermal (between 6000 and 9000 years ago), with the Holocene Thermal Maximum occurring somewhere between 8000 and 10,000 years ago (Kaufman et al. 2004:537), the Neoglacial (5000 to 6000 years ago), the onset of modern plant communities (between 3000 and 4000 years ago), the Medieval Warm period (600 to 1050 years ago/ca. AD 900 to 1350) and the Little Ice Age (100 to 600 years ago/ca. AD 1350 to 1900) (Mann et al. 1998:112).

Near the end of the Pleistocene, during the Last Glacial Maximum, the Alaska Peninsula was covered by glaciers, with alpine valley glaciers in the lowlands, and conjoining ice caps off the Pacific coast and in Cook Inlet forming a continuous ice front (Detterman 1986:160-161). Various lakes on the Peninsula, such as Iliamna, Naknek, Becharof, and Ugashik are all remnants of larger glacial age lakes that were created when moraines captured melt water as the glaciers retreated (Detterman 1986:161). Additional evidence of the Peninsula's formerly glaciated existence are outwash plains, moraines, kettle topography, erratics and glacial striations, and chatter marks on rock outcrops (Detterman 1986:162-163; Laybolt 2000, field observation), as well as seafloor sediments all of which indicate that between 15 and 20 glaciations scoured the Alaska Peninsula (Mason et al. 1997:9).

Recent research indicates that the Lake Clark Valley, north of the study area, was ice free around 13,000 years B.P. (Heiser 2006), earlier than was determined for other areas on the Peninsula (Detterman and Reed 1973), with their final retreat not occurring until the early Holocene (ca. 10,000 years B.P.). With the onset of the Holocene, the climate in the GOA was characterized by long periods of stability, punctuated by shorter periods of instability. Pollen data indicates there were four divisions of the Holocene characterized by different climate regimes as explained in Table 2.1.

Table 2.1 Climate Fluctuations During the Holocene and their Associated Dates.

Climate Regime	**Temperatures**	**Date***
Initial Holocene	-warmer than present	10,000 to 8000 B.P.
Hypsithermal	-warmer than present -1-2° C warmer than previous 2000 years -drier summers than present	8000 to 6000 B.P.
Transitional Interval	-increasing coolness -higher precipitation levels	6000 to 4000 B.P.
Neoglacial	-continued cooling trend -increased precipitation trends	4000 to 3500 B.P.

***Dates from Mann et al. 1998**

Since the inception of the Neoglacial, which is ongoing, several shorter climatic fluctuations have occurred. In the Kenai Mountains there is evidence of four tide water glacial expansion episodes after 4000 years ago, and a fifth advancement between ca. 1300 and 1800 (AD 100 to 600), with a major advancement in southern Alaska between 1300 and 1400 years ago (AD 550s to 720s) (Barclay, et al. 2009:2034), and a full retreat by 900 years ago (ca. AD 1000). Around 900 years ago (AD 1000) the onset of the Medieval Warm Period (MWP) is detected through proxy climate records found in ice core data, as is the subsequent onset of the Little Ice Age by about 500 to 700 years ago (AD 1180s to the 1320s), which culminated in two advance phases about 400 years ago, in the 1540s to the 1710s, and again almost 200 years ago, in the 1810s and 1880s (Barclay et al. 2009:2040). Extreme glacial and tidewater glacial retreats began about 100 years ago (AD 1900).

On the east side of the Kenai Mountains other maritime glacial advance episodes occurred from AD 1420 to 1460, 1640 to 1670, 1750 and 1880 to 1910. Land terminating glaciers also advanced between AD 1440 to 1460, 1650 to 1710, and 1830 to 1860. The difference in timing between the two areas is due to maritime versus continental climate conditions (Mann 1998:28; Mann et al. 1998:114).

2.7 Modern Environment, Climate and Weather Conditions

2.7.1 Atmospheric Conditions

Due to the Aleutian storm track, southwest Alaska experiences severe and variable weather patterns. Winds come into the Gulf of Alaska from the south in the eastern portion of the Gulf, while the central Gulf is dominated by easterly winds. Semi-permanent atmospheric features of the Gulf are the Aleutian low-pressure regions, the east Pacific high-pressure region and the Siberian high-pressure system (Wilson and Overland 1989: 32). The Aleutian low (AL) is caused by storm systems and it is actually a statistical low, as the "average monthly sea-level pressure along the Aleutian chain is lower than surrounding areas (Wilson and Overland 1989:32). Between the months of August and December the AL moves into the Gulf of Alaska from the west, returning to the western Aleutians in January, after which it weakens through to July (Bennett et al. 2006; NOAA 2012; Wilson and Overland 1989:33). During this time the cyclonic low-pressure systems are also weakened and migrate further to the north due to a decrease in the difference between equatorial and polar temperatures (Wilson and Overland 1989:33). The AL has a strong, widespread effect on the climate in the Pacific Northwest, influencing winter storms, precipitation, and surface temperature over North America as its location and strength changes (Spooner et al. 2003:77). During its eastern placement in the Gulf of Alaska the AL exerts its greatest area of influence, transferring warm, moist air to the west coast (Spooner et al. 2003:77).

With the absence of the AL during the summer months, the east Pacific high moves northward from its usual coastal California location, and is established in the Gulf, dominating the entire Pacific coast of North America between June and August bringing warmer temperatures (Wilson and Overland 1989:33). From October to March the Siberian high-pressure system influences the Gulf of Alaska. It is comprised of a large pool of cold air over eastern Asia and northern Alaska and its influence, although it is rarely actually in the Gulf of Alaska, is felt when there is a southern shift of the Aleutian storm track, bringing cold winds from the north into the area (Rodionov et al. 2005; Wilson and Overland 1989:33).

2.7.2 Weather Patterns

Presently, the Gulf of Alaska is an ice-free zone which is a result of the Alaska Current moving warmer water into the area, and northward moving cyclonic storms that, release precipitation and latent heat. The combination of these factors results in weather patterns that are "dominated by the interactions between ocean-current patterns and west-to-east movement of major weather systems" (Mann 1998:28), creating a maritime climate with mild temperatures and high amounts of precipitation which increase towards the east (Mann 1998:28).

2.7.3 Ocean Currents

The Alaska Coastal Current runs from British Columbia to Unimak Pass in the Aleutians, moving warmer waters into the Gulf (Hood 1986:6; Mann 1998:28). Offshore, the Alaska Current, created by the bifurcation of the North Pacific Current, dominants the water transport system in the Gulf, moving surface water parallel to the continental shelf. To the west of Kodiak, this current becomes the Alaskan Stream (Hood 1986:6). The Alaska Current/Alaska Stream "is the eastern and poleward boundary of the large-scale, counter-clockwise rotating subarctic gyre", the Alaska Gyre, encompassing the northern portion of the larger Pacific Ocean current system (Reed and Schumacher 1989:59; Schumacher et al. 1989).

The Alaska Gyre creates a system of water downwelling. Downwelling in the Gulf of Alaska is generated by a combination of strong along shore winds and low temperatures and high water salinity, which causes the upper layers of water to be of greater density, resulting in water column instability and mixing with deeper waters (Mueter 2004). Although downwelling is usually associated with lower biological productivity of ocean waters, the reverse is true in the Gulf of Alaska (Mueter 2004).

2.8 Vegetative History

Past vegetation and climate regimes are most frequently reconstructed using pollen data derived from sediment cores taken from the bottom of lakes and peat bogs. Pollen and spore presence is used to establish vegetation distribution patterns, or the vegetation biogeography of an area. The presence and association of specific plant types indicates the past environmental conditions and, when associated with an archaeological deposit enables researchers to gain insight into climate conditions during past human occupations.

2.8.1 Pollen Data from the Region

There are few reconstructions of the Holocene environment of southern Alaska and those that do exist, show discrepancies in the timing of palynological changes between maritime and continental sites. These are attributed to a shift in the location of the maritime and arctic air masses and storm paths inland (Spooner et al. 2003:78). Along the Alaska, Yukon, British Columbia border there is evidence for the late onset of the Neoglacial (ca. 1800 years BP) due to "an increase in the frequency of the inland penetration of low pressure cells and coincident precipitation" (Spooner et al. 2003:78), although the effects of low pressure cell movement on the study area during the Neoglaciation are indeterminate. Moreover, a review of the Little Takli Island pollen sample analysis reveals that Spooner et al.'s (2003) findings are not replicated; there is no western hemlock (*Tsuga heterophylla*) pollen in the Takli Island profile (Bigelow 2001).

Heusser's (1960:184) analysis of pollen cores from along the Alaska Peninsula and on Kodiak Island indicates a poor representation of coniferous trees on the Kenai Peninsula and an absence on Kodiak during the Hypsithermal, while alder and birch succeeded early after the post-glacial fern-sedge-umbellifer vegetation on the Kenai Peninsula. Heusser (1960) concluded that during the Hypsithermal the climate was warm and moist in the area becoming drier over time, with an intervening episode of humidity. Following the Hypsithermal the area was dominated by alder, birch and Sitka spruce with an eventual dominance of birch (Heusser 1960).

2.8.2 Little Takli Island Pollen

Local paleoenvironmental conditions were extrapolated from a palynological analysis of a stratified column collected by Hilton (2002) from a peat bog located less than one kilometer from Mink Island, on what is informally referred to as Little Takli Island (Hilton 2002:49) (see Figure 2.3 for a diagram of pollen origins). Little Takli Island is approximately 22 hectares or 55 acres in size. It is covered by vegetation similar to Mink Island, possessing moist tundra with grasses (*Poaceae sp.*), sedges (*Carex sp.*), herbaceous plants, *Vaccinium sp.* plants, heaths, and with less than 20 % of the island supporting alder and willow shrubs, neither of which are found on Mink Island (Hilton 2002).

Hilton (2002) chose the peat bog for a pollen profile as its stratigraphic profile was fully exposed along the north shore of Little Takli Island, enabling examination and facilitating removal of a column sample. This profile was first sampled and dated during the Exxon Valdez Oil Spill Archaeological Damage Assessment (Dekin et al. 1993).

Two split samples of charcoal taken from between 210 and 250 cm below the surface in the profile returned uncalibrated radiocarbon dates of 9340 ± B.P. (GX-17272), 9575 ± 265 B.P. (GX-17273), 10,940 ± 310 B.P. (GX-17271) and 11,160 ± 370 B.P (GX-17270) (Dekin et al.1993:124 and 133).

As the peat bog is situated atop bedrock altered by Pleistocene glaciation, Hilton (2002) postulates that the shoreline of Katmai was likely ice-free by around 11,000 years ago (Hilton 2002:51-52). Hilton (2002:59) dated uncharred herbaceous material taken from individual peat samples in an attempt to eliminate radiometric reversals or perturbations associated with woody material. Each fragment was examined so as to remove any modern root material that may have influenced the dates obtained. Hilton's (2002:58) calibrated dates are within the range of Dekin et al.'s (1993) uncalibrated dates, see Table 2.2.

The peat profile contains tephra layers (Hilton 2002:59) but to date these samples remain unstudied. Because of this, the only justifiable approximation is that the tephra

Table 2.2 Peat Column Calibrated Radiocarbon Dates.

Laboratory Designation	**Depth (cmbs)**	**Calibrated Age Range (BP)**
CAMS-60630	33	470-290
CAMS-60631	63	2,710-2,340
CAMS-60632	91	3,135-2,850
CAMS-60633	123	4,965-6,660
CAMS-61256**	151	3,380-3,075
CAMS-60634	189	7,585-7,425
CAMS-60635	213	8,585-8,385
CAMS-60636	223	10,145-9,630

Discarded as too young based on its stratigraphic position (adapted from Hilton 2002:58)

located in top 20 cm of the profile is from the 1912 Katmai eruption as this ash is found as a shallow deposit throughout the region. Sandy stringers in the peat profile were likely caused by aeolian deposition and may be evidence of increased storminess during the Neoglaciation (Hilton 2002:61).

Samples from the peat column were submitted to Dr. Nancy Bigelow of the Alaska Quaternary Center at the University of Alaska Fairbanks, where she prepared, identified and analyzed the pollen samples; all procedures are discussed in Bigelow (2000). Pollen percentages were calculated using two different pollen sums, with percentage terrestrial tree, shrubs and herbs calculated by using the sum of these taxa, while the percentage of spores was calculated using the sum of the pollen sum and the sum of the spores, thus preventing spores from dominating the terrestrial pollen count (Bigelow 2000:2). Figure 2.3 illustrates the pollen frequencies from the Little Takli Island profile and Table 2.3 describes the different pollen zone and their associated vegetative communities.

The Little Takli Island profile is similar to pollen data from outlying areas. On the northern side of the Alaska Peninsula, using pollen records from Idavain and Snipe Lakes, Brubaker et al. (2001) found *Alnus/Betula* shrub tundra dominated the southern region from 8000 radio carbon years (rcy) B.P. to present, while *Alnus/Picea* was dominant at the same time in more northerly regions of southwest Alaska.

Similar frequencies appear on western Kodiak at the Boundary Creek Kettle. Zone 1 here dates to about 4260±110 rcy ago and has high *Alnus* frequencies in the basal 1 cm, after which grass pollen increases at the expense of the *Alnus* within the next 10 cm

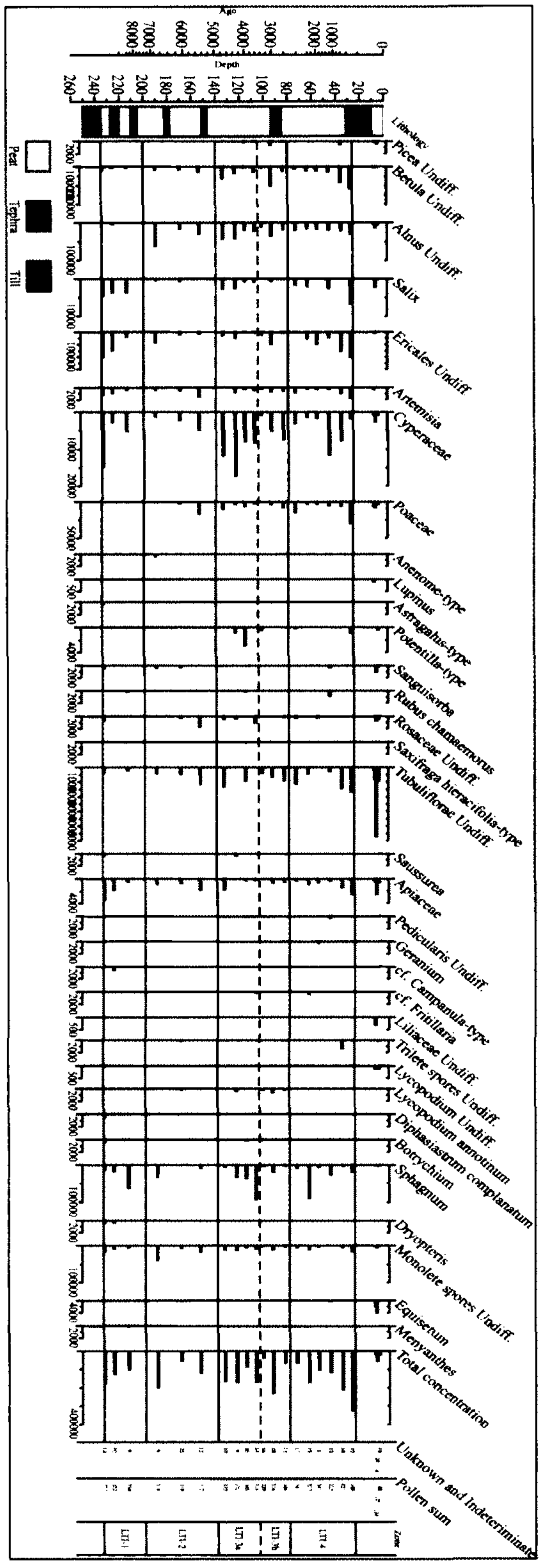


Figure 2.3 Little Takli Island pollen profile, from Bigelow 2001.

Table 2.3 Little Takli Island Pollen Profile Description.

Pollen Zone	Depth (cm)	Radiocarbon Date (BP)	Pollen Description
LTI-1	250-200	8800-7500	-high amounts of *Ericales* (heath) pollen -some *Betula* and *Sphagnum* -*Ericales-Betula* shrub tundra interspersed with sedge and *Sphagnum*
LTI-2	200-140	7500-5000	-*Alnus* abundance, increasing *Betula*, decreasing *Ericales* -continuation of *Cyperaceae* and *Sphagnum* pollen -*Alnus-Betula, Ericales* shrub tundra is present with expanding *Graminoid* tundra
LTI-3a	140-105	5000-3600	-*Betula* and *Alnus* dominance -increases in *Cyperaceae*, *Poaceae*, and *Sphagnum* -decrease in *Ericales*
LTI-3b	105-80	3600-2700	-increasing *Ericales* -decreasing *Sphagnum* -continued *Betula-Alnus* vegetative community with greater amounts of Ericales
LTI-4	80-26	2700-300	-increasing *Betula*, *Alnus*, and Ericales -variable frequencies of *Sphagnum* -*Betula*-Ericales-*Alnus* shrub tundra
Uppermost section	26-surface	300 on	-low frequencies of *Betula* and *Ericales* -increase in *Alnus* and herbaceous pollen -*Alnus* shrub tundra ecosystem with abundant grasses and weeds

(Nelson and Jordan 1988:61). Zone IIa dates ca. 2330 rcy ago and illustrates a marked decrease in *Alnus* pollen (down to 10 %) with a concomitant rise of grasses (40 to 50 %) and sedges (20 to 30 %), and a constant in heath pollen at about 5 % of the sum (Nelson and Jordan 1988:61). Zone IIb dates ca. 1630±60 rcy and is differentiated from Zone IIa only by a decrease in the number of fern spores found, while the uppermost portion of Zone II represents herbaceous plants with stable *Alnus*, Poaceae and Cyperaceae counts (Nelson and Jordan 1988:61). This Kodiak Island sample is different as are the species of grass pollen present. The value of this comparison is weak though as the Kodiak sample is similar to Little Takli Island only in its arboreal pollen count; the grass frequencies are poorly dated with only a few dates for the entire column.

Spatially, the closest pollen data for the Alaska Peninsula was taken from the Naknek River Drainage. Samples taken from this area also display similar pollen frequencies, with *Alnus* and *Betula* dominating the arboreal pollen frequencies after about 3500 rcy B.P. at Naknek Lake, Smelt Creek and Brooks River Sites (Heusser 1963).

Generally, the entire region displays similar trends in terms of arboreal (tree) pollen frequencies, but there are marked differences in Gramieae/Poaceae (grass species) frequencies and at Little Takli Island in particular. It is likely that these differences are a reflection of strong winter winds and summer storm winds that inhibit the growth of anything larger than shrub or bush vegetation.

These analyses serve as only general guidelines for estimating past vegetative trends because of the different depositional environments from which the data were recovered. Little Takli Island and Kodiak Island samples were derived from peat bogs, while those of northern, southwest Alaska come from lake beds (Brubaker et al. 2001), three from the Naknek Drainage are from muskegs and four are from archaeological excavations (Heusser 1963). Peat bog pollen deposits more closely mirror their local environments, while lakes serve as reservoirs for sediments and pollen and express a more regional picture of the pollen rain. As Dincauze (2000:345) warns, neither are not "a truly representative picture of vegetation associations at scales (re: localized) important to people living nearby" (Dincauze 2000:345).

As playnology is one of the few means by which to gain insight into past vegetation, despite its lack of direct association in this case, it is an important indicator of past vegetation patterns on Mink Island and subsequently, an indicator of past temperature and moisture regimes.

2.9 Present Vegetation

The Aleutian Range divides the broadly defined northern Alaska Tundra ecosystem and the southern, interior Marine West Coast Forest and the coastal Taiga ecosystem. Katmai National Park and Preserve includes all of these ecosystems and is characterized by four vegetation types; closed spruce/hardwood forest, moist tundra, shrub thickets and alpine tundra (Viereck and Little 1972).

The northern Alaska Tundra on the northern side of the Aleutian Range, contains the 'Lake Region' which is dominated by closed spruce/hardwood forests, with a canopy comprised of white spruce (*Picea glauca*), black spruce (*Picea mariana*), paper birch (*Betula paprifera*), in upland areas, and balsam poplar (*Populus balsamifera*) on floodplains (Viereck et al. 1992). The understory consists of numerous lichen (*Sphagnum* spp.), and shrub species such as Labrador tea (*Ledum groenlandicum* or *decumbens*) and blueberry and cranberry (*Vaccinium sp.*) species (Viereck et al. 1992). On the extreme western edge of the park forested lake and river sides trend to wet tundra and glacial outwash that characterizes the Bristol Bay Coastal Plain.

Along the Pacific coast and the Shelikof Strait, coastal alder thickets are interspersed with willow (*Salix sp.*), birch (*Betula sp.*), and Sitka spruce (*Picea *stitchensis*). Sitka spruce, identified in Amalik Bay and Kuliak Bay, is the only coniferous tree species that has advanced this far southwest (Heusser 1960).

Sand and gravel beaches along the Strait and on islands within it contain herbaceous communities, as well as different *Rubus* species (i.e. berry plants from the rosaceous genus, i.e. raspberries) including Salmonberry (*Rubus spectabilis*) (Cahalane 1959; Viereck et al. 1992).

Table 2.4 Common Vegetation in Katmai National Park and Preserve.

Common Name	**Scientific Name**
White spruce	*Picea glauca*
Balsam poplar	*Populus tacamahaca*
Willow species	*Salix sp.*
Alder	*Alnus sp.*
Lichens	*Cladonia sp. (one of many)*
Grasses	*Poaceae sp.*
Sedges	*Carex sp.*
Irises	*Iridaceae*
Orchids	*Orchidaceae spiranthes roman zoffiana*
Arctic willow	*Salix artica*
Sitka spruce	*Picea sitchensis*
Kenai birch	*Betula kenaica*
Dock	*Rumex fenestratus*
Mountain sorrel	*Oxyria digyna*
Cloud berry	*Rubus chamaemolus*
Salmonberry	*Rubus spectabilis*
Nagoon berry	*Rubus stellatus*
Lupines	*Luinus sp.*
Crowberry	*Empetrum nigrum*
Fireweed	*Epilobium angustifolium*
Cow parsnip	*Heracleum lanatum*
Labrador tea	*Ledum palustre L. subsp. Decumbens*
Mountain cranberry	*Vacinium vitis-idaea*
Bilberry	*Vaccinium ovalifolium*
Bog blueberry	*Vaccinium uliginsum*
Mountain heaths	*Phyllodoce sp.*
Rye grass	*Elymus arenarus*

Alpine tundra is found at higher elevations and where the slope, aspect, and soil are suitable. Alpine tundra is characterized by dwarf scrub (*Ericaceous sp.*), mountain heaths (*Phyllodoce sp.*), *Vaccinium* species and avens (*Geum sp.*). Lowlying, poorly drained areas are characterized by moist tundra ecosystems, here dominated by herbaceous species along with willow (*Salix sp.*), dwarf birch (*Salix x cotteti*), and sedges (*Carex sp.*). See Table 2.4 for a list of species common to Katmai National Park.

2.9.1 Mink Island Vegetation

Below, in Table 2.5, is a list of the plant species identified at Mink Island by the author during the 2000 field season as well as those by Hilton (2002:119). A small number of these species were utilized by native populations for medicinal or subsistence value. These include cow parsnip, Labrador tea, crowberry, yarrow and bog blueberry.

Table 2.5 Vegetation on Mink Island.

Common Name	**Scientific Name**
Cow parsnip	*Heracleum lanatum*
Labrador tea	*Ledum groenlandicum*
Crowberry	*Empetrum nigrum*
Wild iris	*Iris setosa*
Lupine	*Lupinus arcticus or nootkatensis*
Shagnum mosses	*Sphagnidae spp.*
Fireweed	*Epilobium angustifolium*
Goldenrod	*Solidago mulitradiata*
Grasses	*Poaceae sp.*
Horsetail	*Equisetum sp.*
Bunchberry	*Cornus canadensis*
Bog blueberry	*Vaccinium uliginosum L.*
Coastal paintbrush	*Castilleja unalaschensis*
Tall jacob's ladder	*Polemonium acutiflorum*
Grass of Parnassis/Bog star	*Parnassis palustris*
Bog candle	*Platanthera dilatata*
Alder	*Alnus sp.*
Northern geranium	*Geranium erianthum (small portion)*
Fern	*Polystichum sp., Gymnocarpium sp., Athyium sp. ???*

2.10 Terrestrial Resources

2.10.1 Land Mammals

There are 30 indigenous land mammals on the Alaska Peninsula, these include beaver (*Castor canadensis*), muskrat (*Ondatra zibethicus*), porcupine (*Erethizon dorsatum*), the tundra hare (*Lepus othrus*) and the snowshoe hare (*Lepus americanus*), Grey wolf (*Canis lupus*), brown bear (*Ursus arctos*), red fox (*Vulpes vulpes*), marten (*Martes americana*), mink (*Mustela vison*), and the land otter (*Lutra canadensis*), lynx (*Lynx canadensis*), caribou (*Rangifer tarandus*), and moose (*Alces alces*) (Cook and MacDonald 2005; Mobley et al. 1990). Caribou are limited on the south side of the Aleutian Range and calve outside Katmai Park along Bristol Bay, after which they migrate to the southwest along the Peninsula. Moose are common in the interior portions of the Peninsula, and are found as far southwest as Port Moller.

On Mink Island only two of these species are present, mink and the occasional visiting brown bear. Mink inhabit the island year round, while bears often swim from Takli Island to Little Takli Island, crossing over to Mink on the low tide tombolo in search of clams.

2.10.2 Birds

Birds of Katmai are numerous due to the varied habitats available for habitation. Large inland species include Bald eagles (*Haliaeetus leucocephalus*) (which migrate here in the spring) the American gyrfalcon (Falco rusticolus), the willow ptarmigan (Lagopus lagopus), and the rock ptarmigan (Lagopus mutus), several owl species (*Bubo* *virginianus, Nyctea scandiaca, Strix nebulosa*), and ravens (Corvus corax). In conjunction with these there are several other smaller species of song birds found in the park as well as several species that migrate into the area during the summer months (Cahalane 1959; Mobley et al. 1990; SWAN 2007). For a complete species list refer to Southwest Alaska Network Inventory and Monitoring Program (SWAN 2007).

Over 147 species of shore birds inhabit the Gulf of Alaska seasonally. There are loons (*Gavia spp.*), grebes (*Podiceps sp.*), oyster catchers (*Haematopus sp.*), sandpipers (*Tringa sp.*), plovers (*Pluvialis sp.),* puffins (*Fratercula sp.*), guillemots (*Cepphus sp.*), murres (*Uria sp.*), murrelets (*Brachyramphus sp),* gulls (*Larus sp.*), tundra swans (*Cygnus columbianus*), cormorants (*Phalacrocorax sp.*) and several duck species including mergansers (*Mergus sp.*), mallards (*Histrionicus histrionicus*), and goldeneyes (*Bucephala islandica*) (Cahalane 1959; Mobley et al. 1990; Ruthrauff et al. 2007; SWAN 2007).

2.11 Aquatic Resources

2.11.1 Lacustrine and Riverine Fish

Kashivk, Katmai, Dakavak, Amalik, Kinak, Missak, Kuliak, Kaflia, Kukak, Hallo and Kaguyak Bays, all within Katmai Park and Preserve, are outlets for numerous small streams and rivers. The majority of these are small and unnamed, but exceptions are larger rivers such as Katmai River, Alagogshak and Soluka Creeks (which all flow into Katmai Bay), Mageik and Martin Creeks (that flow into Katmai River) and north of Hallo Bay the Park's two largest rivers, Big and Swikshak. A considerable number of smaller glacial streams have irregular flow or unstable stream beds, and drain steep cliff slopes (Heard et al. 1969:4-5). Most of the streams and rivers that drain into the Shelikof Strait are short and steep, but some do drain lakes with benthic habitats able to support fish populations (Heard et al. 1969:5). The largest anadromous fish run on the Shelikof side is at the head of Kalifa Bay. Two smaller ones occur at Kuliak Bay and there is a third in a small stream that runs parallel to the Swikshak River (Heard et al. 1969:8-9).

On the Bristol Bay side of the Alaska Peninsula and Katmai National Park the 'Lake Region" (Naknek and Brooks Lake drainages, Grosvenor Lake, Grosvenor River, Coville Lake, Coville River, American Creek) supports a greater variety and number of fish populations as the rivers and lakes here are larger and deeper than those on the southern side of the Peninsula (Heard et al. 1969:4). Becharof Lake, Egegik River and Ugashik Lake and River are outside of the Park although Naknek's outlet into Bristol Bay originates within the Park. Table 2.6 list fish populations identified in the rivers and lakes on the Naknek side and the Shelikof side of the Alaska Peninsula.

2.11.2 Marine Mammals

Several marine mammal species make their home in the Gulf of Alaska and off the shores of Mink Island and the extensive use of these by past occupants is evident in the faunal material from the site (Murray 2004a, 2004b) as seal remains are the most common mammal represented in the entire faunal collection. Northern fur seals (*Callorhinus ursinus*) migrate through the Gulf on their way to their breeding grounds around the Pribilof Islands. They appear in spring and early summer, and are absent until their return migration between August and October (Cahalane 1959; Mobley et al.

Table 2.6 Fish in Katmai National Park and Preserve (Jones et al. 2005).

Common Name	**Scientific Name**
Humpback whitefish	*Coregonus pidchian*
Arctic grayling	*Thymallus arcticus*
Sockeye salmon (Red)	*Oncorhynchus nerka*
King salmon (Chinook)	*Oncorhynchus tshawytscha*
Pink salmon (Humpback)	*Oncorhynchus gorbuscha*
Chum salmon (Dog)	*Oncorhynchus keta*
Coho salmon (Silver)	*Oncorhynchus kisutch*
Rainbow trout	*Salmo gairdnerii*
Dolly Varden	*Salvelinus malma*
Lake trout	*Salvelinus namaycush*
Arctic char	*Salvelinus alpinus*
Alaska blackfish	*Dallia pectoralis*
Northern pike	*Esox lucius*
Burbot	*Lota lota*
Least cisco	*Coregonus sardinella*
Pond smelt	*Hypomesus olidus*
Round whitefish	*Prosopium cylindraceum*
American shad	*Alosa sapidissima*
Arctic lamprey	*Lampetra camtschatica*
Brook lamprey	*Lampetra alaskensis*
Eulachon	*Thaleichthys pacificus*
Pacific lamprey	*Lampetra tridentata*
Pacific staghorn sculpin	*Leptocottus armatus*
Slimy sculpin	*Cottus cognatus*
Threespine stickleback	*Gasterosteus aculeatus*
Pygmy whitefish	*Prosopium coulterii*

1990:35). Stellar sea lions (*Eumetopias jubatus*) inhabit the waters near Mink Island, with a sea lion haul-out within five kilometers of the site. Harbour seal (*Phoca vitulina*) are present year round, and today have large haul-outs in Kukak Bay, Wide Bay and Puale Bay (Cahalane 1959). Also present are sea otters (*Enhydra lutris*), with populations rebounding after near extinction earlier in the 20th century, and their prehistoric use is evidenced in the Mink Island faunal assemblage (Murray 2004a, 2004b).

Cetaceans are also present in the Gulf of Alaska and the Shelikof Strait during various times of the year. Seven types of baleen whales pass through the Gulf including grey (*Eschirchtius robustus*), humpback (*Megaptera novaeangliae*), minke (Balaenoptera acutorostrata), sei (*B. borealis*), fin (*B. physalus*), blue (*B. musculus*), and right (*Balaena glacialis*) whales. The number of whales that pass through the Shelikof Strait is unclear, most whales pass through the Gulf on the southern side of Kodiak Island. More common in the Shelikof Strait are toothed cetaceans, the, harbour porpoise (*Phocoena phocoena*), and Dall porpoise (*Phocoenoides dalli*), Pacific white-sided dolphin (*Lagenorhynchus obliquidens*), and on occasion belugas (*Delphinapteris leucas*), sperm whales (*Physeter catodon*), and killer whales (*Orcinus orca*), although like the baleen whales, these species are more common around Cook Inlet, the southeastern side of Kodiak and in Prince William Sound (Mobley et al. 1990).

2.11.3 Marine Fish

Epipelagic fish in the Gulf of Alaska include the Pacific herring (*Clupea harengus pallasii*), sockeye salmon (*O. nerka*), pink salmon (*Oncorhynchus gorbuscha*), chum salmon (*O. keta*), and capelin (*Mallotus villosus*) (Mobeley et al. 1990). Coastal, deep water fish of the area include Pacific cod (*Gadus macrocephalus*), Pacific halibut (*Hippoglossus stenolepis*), Yellowfin sole (*Limanda aspera*), Rock sole (*Lepidopsetta bilineata*), Great sculpin (*Myoxocephalus polyacanthocephalus*), and a variety of greenling (*Hexagrammos sp.*) (Mobley et al. 1990).

2.11.4 Littoral Shellfish

Species distribution depends largely on water salinity, substrate composition, the presence or absence of shore fast winter ice and water temperature. Extremes in water salinity inhibit shellfish occupation, as does ice scouring during the winter months (Haggarty et al. 1991).

At Mink Island, the intertidal zone contains three classes of molluscs: Bivalvia, Gastropodia, and Polyplacophora with Echniodermata (phylum) sea urchins often found in archaeological middens (Haggarty et al. 1991:72; Hilton 2002:46). Of these different classes, species identified along the shores of the island during excavations in 2000 included limpets (*Acmaea spp.*), chitons (*Katherina tunicata*), bay mussels (*Mytilus trossulus*), dogwinkle whelks (*Nucella lamellose* and *Nucella lima*), butter clams or the smooth Washington clam (*Saxidomus giganteus*), littleneck clam (*Protothaca staminea*), and barnacles (*Balanus spp.*). These different shellfish were observed primarily on the southern side of the Island and many bivalve shell fragments were found on the sand bridge connecting Mink Island to Little Takli Island during low tides.

Identified shellfish remains from the midden on Mink Island include 28 species (Foster 1998, 2000), the greatest number of which were butter clams, littleneck clams, mussels, snails, dogwinkle whelks, Nuttall's cockle (*Clinocardium nuttallii*), and chitons, with horse clams (*Tresus capax*), softshell clam (*Mya truncata*), limpets, and razor clams (*Siliqua patula*) in lesser amounts.

2.12 Summary

This chapter summarizes the climate history, the potential sea level history, the development of the vegetative landscape at Mink Island and the geological and environmental processes that can affect site formation processes and can create post-depositional alterations of the deposit. Tectonics and volcanic activity have altered the landscape and its productivity throughout time and because of this, human populations have been impacted with respect to resources and suitable locations for habitation. As the premise of this dissertation is to examine changes in the archaeological deposit, as well as possible reasons for site abandonment, it is important to have a clear understanding of all large scale environmental events that might have affected site formation, as well as what may have drawn people to occupy the location.

Chapter 3

Archaeology and Culture History on the Alaska Peninsula, the Kodiak Archipelago and Outer Cook Inlet

3.1 Introduction

Although this project is not directly related to culture change in southwest Alaska, it does have implications for our understanding of archaeological site formation processes there, and for understanding the impact of climate change on the past occupants in the region. The Mink Island site did not exist in a cultural or ecological vacuum, and knowledge of changes in material culture, and settlement and subsistence pursuits must be understood if observations described here are to be placed within the larger regional context.

To facilitate a coherent description of the cultural setting in the study area, the physical landscape is divided into three general areas, the Pacific Coast of the Alaska Peninsula and Kodiak Island, the interior of the Alaska Peninsula (the Naknek and Ugashik River drainages), and outer Cook Inlet (see Figure 3.1). These general geographic divisions include vast regions that have been subject to little archaeological research. Of the small portions that have been investigated the extent of archaeological coverage varies; areas like the Naknek River Drainage have been the subject of extensive research programs for several decades (see Dumond 1969, 1971, 1974, 1987a,b, 1991, 2008), while others for instance along the Shelikof Strait coast, have been subject to only limited investigation (Clark 1977). Cultural chronologies are developed, but there is an incomplete understanding of the human relationships that existed within and among regions.

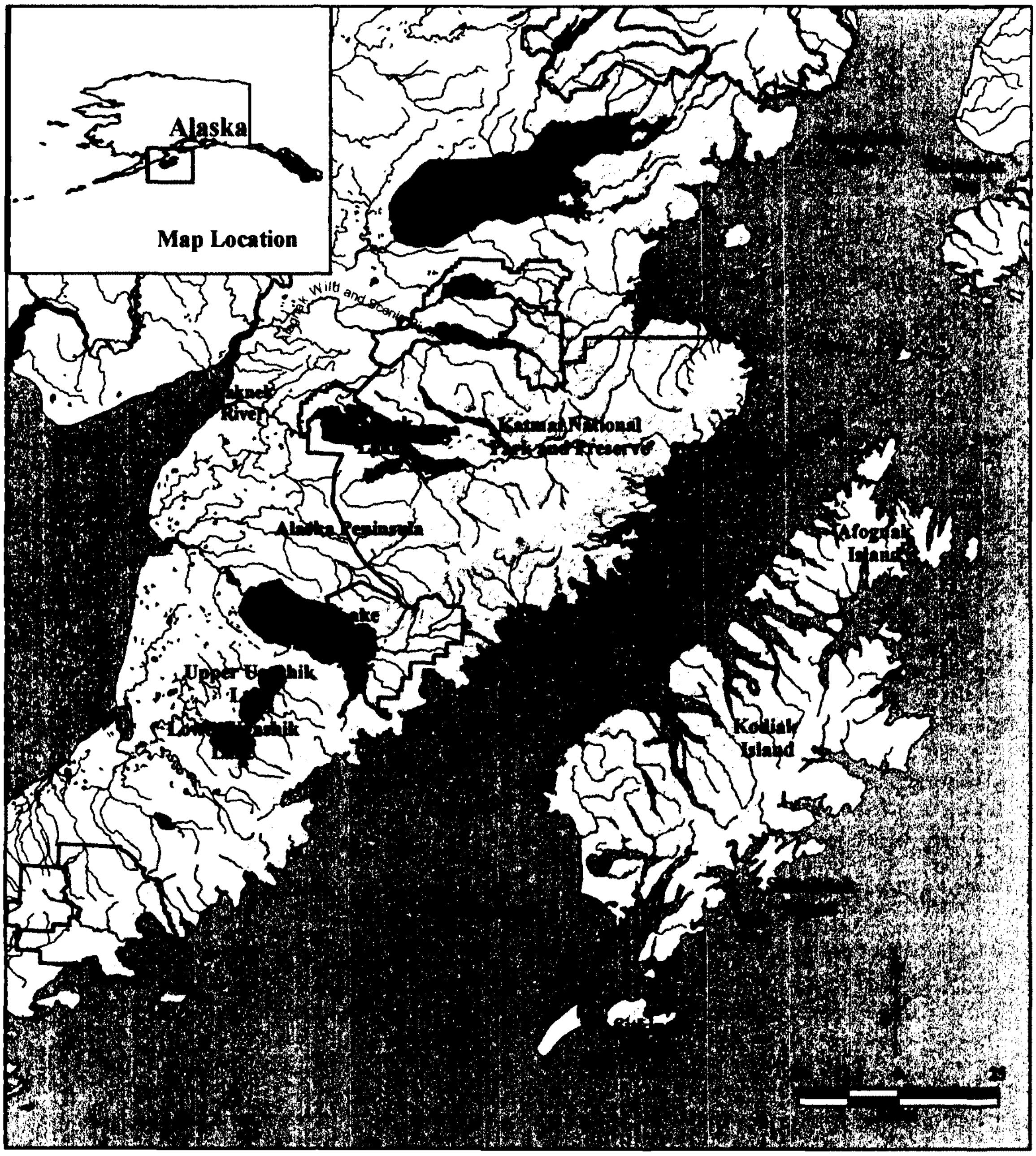


Figure 3.1 Areas of archaeological research in the Gulf of Alaska.

3.2 Prehistory of the Gulf of Alaska

3.2.1 Stage I: Pre-8000 B.P.

3.2.1.1 Naknek and Ugashik River Drainages

The Ugashik Narrows Phase, from the Ugashik River, and the Koggiung Phase, found at the mouth of the Kvichak River and possibly Lake Illiamna and Chignik River area date between are the earliest known cultures on the Alaska Peninsula, dating between 9000 and 7000 B.P. (Dumond 2011; Dumond et al. 1976; Fitzhugh 2003a:89). Both Phases are part of the American Paleoarctic Tradition, with a toolkit possessing microblade and microblade core lithic industry, as well as large flake scrapers (Dumond 1981, 1987a, 1998a; Henn 1978). Site locations indicate a possible interior economy, focusing on hunting caribou and other terrestrial mammals, similar to economies associated with other Paleoarctic peoples throughout Alaska at this time (Dumond 1981, 1987a, 1998a). The Narrows and Koggiung Phases are followed by a hiatus in the archaeological record on the Peninsula that lasts until approximately 5000 B.P.

There are only two sites that represent this period, the Graveyard Point site and the Ugashik Narrows Site. At this time there are no sites of equal antiquity on Kodiak Island, although site 49-SEL-009 in Cook Inlet has material dating between 8170 to7420 years ago and contains chipped stone artifacts (Hilton 2002:75). In Shelikof Strait, Mink Island, with basal dates of 7255 cal B.P. (Beta 110268) (Schaaf 2002) will shed further light on the adaptations and lifeways of early coastal peoples.

3.2.2 Stage II: 8000 to 4000 B.P.

3.2.2.1 Pacific Coast of the Alaska Peninsula and Kodiak Island

Around 7500 cal B.P. the first humans appear on Kodiak Island (Fitzhugh 2004). This period is identified as Ocean Bay I, and artifacts are characterized by chipped stone, with some microblades and microblade cores, and a few ground stone items. Limited faunal material indicates an economy focused on marine resources and fishing (Clark 1979). Ocean Bay I material culture shares a considerable number of traits with Takli Alder, the earliest culture identified on the Pacific coast of the Alaska Peninsula. Takli Alder appears just after Ocean Bay I, and was initially identified at the Takli Island Site, on Takli Island in the Shelikof Strait (Clark 1997; Dumond 1998a). Takli Alder and Ocean Bay I shared attributes including a morphologically similar flaked chert lithic industry, microblades and microblade cores and a paucity of ground slate (Clark 1979). The similarities between the two assemblages indicate close ties between the coast and Kodiak Island at this time.

By 5000 B.P. Ocean Bay I transitions into Ocean Bay II, and there is a divergence between the material culture of the Peninsula and Kodiak Island as Takli Alder shifts to Takli Birch on the Peninsula. Although similarities in ground slate point morphology continue between Birch and Ocean Bay II, Birch contains a high proportion of flaked tools, in addition to large slate bayonets, ground slate ulus, ground slate knives, adze bits, and gouges (Clark 1992b:7). Ocean Bay II peoples nearly abandon the use of chipped stone in favor of ground slate implements, and they discontinue the use of microblades.

In addition, portable structures and robust semi-subterranean sod houses appear in the Ocean Bay II archaeological record (Clark 1979). On Kodiak Island, it appears Ocean Bay peoples harvested a variety of resources across microenvironments including marine hunting, near-shore marine fish, birds, littoral resources and riverine fishing (Clark 2001; Fitzhugh 2003b; Steffian 2001).

3.2.2.2 Naknek and Ugashik River Drainages

Between 5000 and 4500 B.P., the Northern Archaic Tradition dominated the Bering Sea coast of the Alaska Peninsula, as represented by a few Graveyard Phase sites in the Naknek River Drainage and the Ugashik Knoll Phase in the Ugashik River Drainage. Northern Archaic Tradition assemblages are characterized by a lack of microblades, several types of projectile points and a variety of chipped stone tools, and an interior subsistence focus, which, on the Alaska Peninsula is inferred on the basis of site locations suggesting caribou predation (Dumond 1981, 1987a, 1998a; Henn 1978).

From 5000 to approximately 3900 B.P. a variant of the Northern Archaic Tradition emerged in the interior with the Brooks River Beachridge Phase (Dumond 2011). Represented by only a few campsites around the mouth of the Brooks River and the upper portions of the Naknek River, Beachridge sites are identified by lanceolate projectile points (Dumond 1998a:192). Contemporaneous with the Beachridge Phase is another phase of the Archaic, the Brooks River Strand Phase, found in the upper reaches of the Naknek and Kvichak River systems as well as at Iliamna Lake. It is characterized by slate lance heads, stone oil lamps, and caribou remains (Dumond 1971, 1987a, 1998a:193).

A terrestrial subsistence focus likely continued in the Naknek region throughout this period while coastal inhabitants of Kodiak and the Pacific region utilized marine resources, as illustrated at the Mink Island Site (XMK-030) (personal observation Laybolt 2001; Murray 2004a). Microblades and microblade cores decline in use, while ground slate implements rise in popularity as do unifacial tools.

3.2.3 Stage III: 4000 to 2500 B.P.

3.2.3.1 Pacific Coast of the Alaska Peninsula and Kodiak Island

On Kodiak Island, Early Kachemak overlaps with the Late Takli Birch (ca. 3300 to 2500 B.P.) culture found on the Alaska Peninsula. Early Kachemak developed from Ocean Bay II and its appearance is marked by the introduction of the ulu, and toggling harpoon technology, both likely through contact with Bering Sea Coast peoples. Use of earlier harpoon forms continues with an increased use of grooved cobble and notched pebble weights, and labrets appear, likely due to contact with Northwest Coast peoples, and the continued dominance of ground stone versus chipped stone tools (Clark 1998:178).

On the Pacific Coast mainland, following Takli Birch, there is an unexplained hiatus between 2200 to 1800 B.P. (ca. 800 BC to AD 200). This is followed by Takli Cottonwood (ca. 1800 to 1500 B.P.). Despite an unexplained four hundred year hiatus (Clark 1992a; 1998), Cottonwood suggest it developed from Birch with assemblages characterized by finely chipped points, adze bits, barbed and unbarbed slate points, polished slate ulus, oil lamps and fiber tempered pottery (the earliest to appear in the area). Cottonwood also illustrates a considerable affinity with the contemporaneous Norton Tradition on the Bering Sea slope and several diagnostic Cottonwood artifacts are also indicative of the Kachemak phases found on Kodiak Island (Clark 1992b:7). Similarities between these assemblages indicate there was some communication among the peoples of Kodiak, the Pacific Coast, and the Bering Coast of the Alaska Peninsula (Clark 1979:7).

3.2.3.2 Naknek and Ugashik River Drainages

The Brooks River Gravels Phase is present in the Naknek Drainage ca. 3900 to 3000 B.P. The Gravels Phase has close affinities to the Arctic Small Tool Tradition with diagnostic chipped bipoints and knives, burins, the occasional microblade and the complete absence of ground slate, and an economic emphasis on caribou and riverine fish (Dumond 1971, 1987a:129-130,1998a). Despite the contemporaneity of the Gravels and Birch phase on the Pacific coast of the Peninsula, the material culture indicates a lack of contact or communications between the two (Dumond 1998a).

The cultural hiatus between 3000 to 2200 B.P. on the Shelikof Strait side is mirrored on the Bering Sea slope of the Peninsula, after which the Smelt Creek Phase (ca. 2200 to 2000 B.P.) appears in the Naknek region (Dumond 2011:115). Diagnostic Smelt Creek artifacts include side blades, projectile points, and chipped adzes, notched sinkers, stone vessels, ceramics and labrets. The notched sinkers point to the use of net or line fishing, and some sites of this phase are identifiable as fishing camps or stations (Dumond 1987a). Interestingly, despite the occupational hiatus between Brooks River Gravels and Smelt Creek, continuity from one culture to the other is indicated by stone tool morphology.

3.2.3.3 Outer Cook Inlet

The Kachemak Cultures around Kachemak Bay appear around 4000 to 3500 B.P., and they persist in the area until about 1400 years ago (Steffian et al. 2006; Workman and Workman 2010). It is likely they originated on Kodiak Island, as Kachemak assemblages appeared there about 500 years earlier than on the mainland (Klein 1996), and the material culture indicates that they developed directly from Ocean Bay peoples (Fitzhugh 2003b). Over time, Kachemak people became more sedentary and site locations indicate either a marine focus or a riverine one (Haggarty et al. 1991; Klein 1996; Workman 1998). Larger and more numerous sites indicate a population increase and elaborate ritual treatment of the dead and distinctive artistry appears, as does an increase in surplus production and multi-season storage on Kodiak Island (Haggarty et al. 1991:121-122; Steffian et al. 2006).

Kachemak I (the Early Kachemak Period in Kachemak Bay) dates from about 4000 to 2700 B.P. (Haggarty et al. 1991; Steffian et al. 2006; Workman 1998). Diagnostic artifacts include chipped projectile points and ground stone tools unlike the ones made and used by Takli and Ocean Bay peoples, as well as labrets, stone weights, toggling harpoon heads (Clark 1984:139; 1997). Kachemak I people harvested a variety of both marine and terrestrial resources. Among marine mammals, harbor seal, porpoise and lesser whales were taken (Workman 1978:73; Workman 1998:151).

During this period Norton and Arctic Small Tool Tradition influences are found in artifact morphologies and the appearance of pottery on the Peninsula. The Kachemak Period differs from the Takli and Ocean Bay. There is definite evidence of marine resource use as well as exploitation of migratory fish species as indicated by the appearance of fishing camps, notched pebbles believed to be netsinkers, and a predominance of ground slate tools (Clark 1984; Dumond 1987a, 1998a; Haggarty et al. 1991; Workman 1978, 1998).

3.2.4 Stage IV: 1000 to 2500 B.P.

3.2.4.1 Pacific Coast of the Alaska Peninsula and Kodiak Island

On the Pacific coast, ca. 1500 to 1000 B.P., the Kukak Beach Phase is associated with open socket toggling harpoons, confirming a continued use of marine resources as indicated by faunal remains of sea otter, seal, fish (with an increased use of offshore fish such as cod and halibut), shellfish, and land mammals at the Kukak Site. Ground slate tools dominate chipped ones, with chipped points trending to smaller sizes (Clark 1977; Dumond 1998a). Similarities in the material culture of Kukak Beach and Brooks River Falls Phase (ca. 1500 to 1000 B.P.), of the Naknek River Drainage in the interior of the Peninsula (Clark 1977) are indicative of close affinities among peoples throughout the Alaska Peninsula and Kodiak Island, possibly suggesting acculturation of the Kukak Beach by the Falls people (Dumond 1971).

3.2.4.2 Naknek and Ugashik River Drainages

The Brooks River Weir phase sites (ca 2000 to 1500 B.P.) are located along the interior river drainages of the Peninsula. The Weir phase is characterized by contracting stem points, bipoints, chipped adzes, the occasional polished slate knife, the occasional small notched sinker, stone lamps, thin plain, check stamped or cord stamped pottery. There are more permanent sites containing semi-subterranean houses and some, less permanent, surficial campsites. Material culture morphology and workmanship illustrates continuity and outgrowth from the earlier Smelt Creek and a continued subsistence focus on fish and terrestrial mammals (Dumond 1987a).

The Brooks River Falls phase is associated with the Norton Tradition, which is characterized by thick, undecorated pottery, many polished slate ulus and lance blades, stone lamps and numerous small, notched pebble sinkers. It is during this time that the number of small sinkers escalates dramatically indicating possible intensification of fish harvesting (Dumond 1987a, 1998a).

3.2.4.3 Outer Cook Inlet

In outer Cook Inlet, Kachemak II (ca. 1800 to 1200 B.P.) shows more dependence on fishing as seen by the increase in grooved weight plummets, much like the trend on the Alaska Peninsula at the time. Unlike anything found on the Peninsula, distinctive mortuary practices associated with Kachemak II appear. These practices include secondary burials, burials with and without grave goods, burials with perforated and drilled human bone and burials accompanied by human heads, which are thought to be war trophies (Clark 1984:139; Lobdell 1980:33-37; Workman 1978:73).

Stage IV of the cultural chronology in the Gulf of Alaska is most notable for the appearance of the elaborate mortuary practices associated with Kachemak II peoples. It is also marked by continued close affinities between the Pacific Coast of the Alaska Peninsula and the Kodiak Island peoples, as well as among the Brooks River Falls people and their more northerly neighbors of the Norton Tradition.

3.2.5 Stage V: 1000 B.P. to Contact

3.2.5.1 Pacific Coast of the Alaska Peninsula and Kodiak Island

Kukak Mound (ca. 1000 to 500 B.P.) succeeds Kukak Beach. The initiation of Kukak Mound is marked by the appearance of gravel-tempered pottery, oil lamps made of gravel and fiber tempered pottery, bi-notched sinkers, a variety of polished slate projectile points and the almost complete absence of chipped stone implements. There is greater reliance on land mammals as compared to the Kukak Beach peoples, with a concomitant decrease in the importance of shellfish (Clark 1977). Reasons for this shift have yet to be explored or explained. No occupations post dating the Kukak Mound phase have been identified along the Shelikof Strait, until the appearance of Russian settlements. Future survey of the Alaska Peninsula may change this picture.

On Kodiak, from around 3500 B.P., Kachemak continues to develop a regional character. By 2500 B.P., in Late Kachemak (or the Three Saints Phase as it is sometimes called), there is a fluorescence of arts, crafts, and a mortuary cult. This mortuary cult is characterized by the internment in middens, incomplete burials, dismembered and scattered human remains, drilled human bone, artificial eyes in eye sockets, and cut and broken bones which are thought by some to indicate cannibalism (Clark 1975, 1998; Workman 1978:74). Jewelry is abundant as are well-made ground slate points and adzes, in contrast to a near absence of chipped stone tools (Workman 1978:68). Furthermore, the development of the Late Kachemak coincides with the development of extensive exchange networks facilitated by an increase in food surpluses and storage (Steffian et al. 2006:121; Workman 2002).

At around 700 or 600 B.P. [(850 to 950 cal yr B.P. (Mills 1994)] on Kodiak Island, Late Kachemak develops into the historically known Koniag peoples. A sporadic distribution of pottery and a considerable number of stone rubble representing sweat bath sites appear on the southern half of Kodiak Island. House size increases, shifting from single-roomed Kachemak structures, to multi-roomed ones. The practice of whaling also becomes evident, along with an explosion in the number of incised slate figurines. Projectile points are scarce and Kachemak workmanship and art, and the Kachemak mortuary cult disappear (Clark 1968, 1998). The Koniag continue to focus their subsistence on marine and riverine resources, particularly salmon runs.

3.2.5.2 Naknek and Ugashik River Drainages

In the Naknek River Drainage, the Brooks River Camp Phase (1000 to 500 B.P.) replaces the Norton Brooks River Falls Phase, marking the appearance of the Thule Tradition in the area (Dumond 2011). Brooks River Camp is characterized by the absence of chipped stone tools, the use of clay lamps and the appearance of the cold trap entrance to houses (Dumond 1987a:184). Good preservation, likely due to the more recent age of material, illustrates the use of bone and antler, with bone wedges, barbed antler points, bone awls, whalebone wedges and bone waste indicative of bone working (Dumond 1987a:161). Contact among the peoples of the Bering Sea Slope, the Pacific Coast, and Kodiak Island is suggested as the Kukak Mound phase (on the Pacific coast of the Peninsula) and Brooks River Camp phase (in the Naknek Drainage); artifacts are almost identical. There is also congruency between artifacts of the Camp peoples and those of Kodiak Island (Clark 1992b:9; Dumond 1998a) and larger more stable villages appear on the Peninsula.

The Brooks River Bluffs phase (ca. 500 B.P. to contact) is the final prehistoric phase on the northern Alaska Peninsula and is also a continuation of the Thule Tradition. Bluffs is characterized by a lack of dart blades, absence of European trade goods, heavy use of insert blades, polished ulus, pottery (although in lesser amounts), birch bark vessels and harpoons and points made of bone. Both caribou and salmon remains are associated with Bluffs' sites, indicating that a substantial part of the year was spent on the river drainages. A substantial site at the mouth of the Naknek Drainage has been identified, and it contains semi-subterranean houses in a variety of sizes (Dumond 1987a: 169-172).

3.2.5.3 Outer Cook Inlet

The Kachemak Sub-III period occurs between 2300 to 1400 B.P. There is an elaboration of material culture with large weights grooved around the middle and end, stone saws, labrets and clay masks. Flexed burials with artificial eyes appear, and harbor seal and porpoise were common (de Laguna 1975; Workman 1978:74).

The Sub-III period is followed by Kachemak III period. Cultural materials from the Great Midden Site on Yukon Island, the Cottonwood Creek Site in Kachemak Bay, and at the Fox Farm Site on Yukon Island, are the type collections for this period (Workman 1978:74). Kachemak III is characterized by the fluorescence of personal adornments and artwork such as beads, pendants, labrets and figurines, as well as very large, decorative oil lamps with human figures and animals pecked into them (Clark 1984:140; Workman 1978:74). The mortuary cult established in Kachemak Sub-III continues with increased evidence for social inequality, and for a high status of women as evidenced by grave goods (Workman 1978:75). Kachemak III peoples continued to focus on marine resources with an increase in the importance of shellfish and there is a scarcity of both marine and terrestrial mammal remains in deposits (Workman 1978:75).

In later Kachemak sites, there is less elaborate artwork found and by about 1500 years B.P. larger sites on Yukon and Chugachik Islands were abandoned. This may have been due to resource stress brought about by population increase, the onset of the Little Ice Age (Reger et al. 2007:99ff) or, as suggested by Workman and Workman (2010: 93) “a series of small things” such as unusually harsh winters, low resource availability, causing them to leave the area (Klein 1996; Reger et al. 2007; Workman and Workman

2010:93). In any case, around 1400 B.P. the Kachemak people abandoned the area, after which time the Dena'ina Indians moved in (Lobdell 1980:9; Workman et al. 1980:396; Workman and Workman 2010).

On both Kodiak and in the Cook Inlet areas, mortuary elaborations continued throughout this period, with considerable evidence for cannibalism and social inequalities, the continued modification of human remains and the fluorescence of different burial types. However, there is no evidence for an elaborate mortuary complex on the Alaska Peninsula, and there is no evidence for occupation of the Pacific Coast after the Kukak Mound phase. There was a considerable amount of interaction between the Peninsula and Kodiak Island during the Kukak phase as indicated by the presence of morphologically similar artifacts.

3.3 Research History in the Gulf of Alaska

This following section discusses past archaeological and ethnographic research conducted throughout on the Alaska Peninsula, Kodiak Island and the outer Cook Inlet area. Similar to the format used above, I discuss previous research undertaken in the different geographical locations throughout the Gulf of Alaska. However, Kodiak Island and the Alaska Peninsula are discussed separately as Kodiak has received a greater amount of scholarly attention over the last century.

3.3.1 Kodiak Archipelago

Prior to the 1930s there was little Euroamerican interest in the history, ethnography and archaeology of the Kodiak archipelago. The first recorded study of the

Koniag peoples occurred in the early 1800s (Clark 1992a:109; Veniaminov, reprint 1984) and focused on the divergence of native languages on Kodiak. In 1851, Holmberg (1856; Clark 1992a:109), a Finnish collector, excavated objects from a native gravesite, and in the 1870s the French ethnologist Alphonse Pinart (1872) collected various cultural materials from Kodiak Island, including four crania from the Uyak site (Clark 1992a:109-110; Pinart 1872). William J. Fisher, an ethnographer, collected over 400 ethnographic artifacts from Kodiak Island inhabitants, now held at the Alutiiq Museum in Kodiak and at the Smithsonian in Washington D.C., and eventually took up residence on the island until his death in 1903 (Clark 1992a:110).

In the 1930s, full-scale excavations took place on Kodiak under the supervision of Ales Hrdlička. However, Hrdlička was more interested in the peopling of North America than with the prehistory of Kodiak itself. During the field seasons of 1931 and 1937 Hrdlička excavated at the Uyak site with the objective of recovering human remains to elucidate the history of the local people (de Laguna 1946; Hrdlička 1941). Little merit is attributed to his Uyak work because of the unscientific and destructive methods of excavation (de Laguna 1946:204). His crews worked quickly with crude techniques, and minimal record keeping; only a few artifacts were kept as the primary objective was to recover human remains. This lack of contextual information, ignorance of stratigraphy and skewed artifact collection techniques led to unfounded generalizations about the site's history. Hrdlička's conclusions were ultimately rejected because of the inability to produce a site reconstruction or even to plot artifact frequencies through time (Clark 1992a:111-112; de Laguna 1956:202). For example, Heizer (1956) attempted to document the material from the site and likened the Lower levels, for which there is no real stratigraphic information, with Cook Inlet phases of Kachemak I and II, and the Upper level to Kachemak III. However, he was unable to provide a "trait-by-trait correspondence" to either Kachemak I and II or to III (de Laguna 1956:202).

Hrdlička located over 100 sites around the Kodiak Archipelago at places such as Uyak Bay, Larsen Bay, Amook Island, the Karluk River and Karluk Bay, Cape Alitak, Olga Bay, Sitkinak Island, Kaguyak Bay, Kiaviak Bay, Three Saints, Nunamiute, and Sitkalidak Island. At the end of Hrdlička's tenure on Kodiak, there were still numerous unanswered questions regarding the development of the Kodiak peoples, and in particular, the origins of the Koniag and their relationship to earlier occupants.

Research stopped during World War II (Clark 1992a:112), and then in 1952 at Karluk, Milan (1974) found numerous artifacts including items of wood well preserved due to water logging, visible house floors, and a number of human burials (Milan 1974:82-85). Milan identified Karluk's archaeological materials as belonging to the Koniag culture, but concluded that further work was required prior to forming any conclusions about the antiquity of the Kodiak peoples (Milan 1974:85).

Between 1959 and 1964, the University of Wisconsin sponsored the Aleut-Konyag Prehistory and Ecology Project (AKPEP), headed by William S. Laughlin. AKPEP resulted in the excavation of numerous sites including in 1961 the Rolling Bay site on Sitkalidak Island, and in 1962, site KOD-083 at Three Saints Bay. Three Saints is an historic settlement underlain by a prehistoric occupation dissimilar to those at Rolling Bay and in the upper levels, Uyak, but comparable with the pre-Koniag lower levels of

Uyak (Clark 1992a:114). In 1963, AKPEP returned to Kodiak, this time under the direction of Donald Clark, and during this time Clark linked the Three Saints 'pre-Koniag' material with the Kachemak Tradition, placing it temporally between the early and late Kachemak Tradition.

With questions regarding Koniag origins in mind, AKPEP excavated at the Old Kiavak site at Kiavak Bay in 1963. Here, Clark found an intervening layer between the Kachemak material and the Koniag artifacts, and identified another phase, the Kachemak Old Kiavak phase (Clark 1966, 1992a, 1997). In 1963, Clark also described Ocean Bay culture from the Sitkalidak Roadcut Site (KOD-119) (Clark 1966, 1979, 1992a). In 1964 the AKPEP ended but financial support allowed Clark and Workman to continue surveying and conduct subsequent excavations at Marmot Bay and Crag Point (Workman and Clark 1979).

In 1971 Clark and students returned to Kodiak, this time excavating various sites on Afognak Island, such as the Afognak Chert and Afognak Slate sites. These were published in his monograph *Ocean Bay: An Early North Pacific Maritime Culture* (1979) wherein he further delineated this culture and discussed it place as one of the first archaeologically recognized cultures on Kodiak Island and the Alaska Peninsula.

Clark has described a 6000-year cultural chronology for Kodiak that has undergone only minor refinements since originally delineated (Clark 1966, 1970, 1992a; Fitzhugh 2004). In the 1980s, evidence of transitional Kachemak to early Koniag and early Koniag to historic Koniag phases were found during excavations at Old Karluk (KAR-31) and New Karluk (KAR-1). Survey work recorded sites at Uyak, Zachar Bay, Larsen Bay, Sturgeon Bay, Spiridon Bays, Sitkinkak Island and Crag (KOD-044) (Clark 1992a; Jordan 1992; Jordan and Knecht 1988), and excavations occurred at Three Saints, Rice Ridge, Kizhuyak River Site (KOD-190). The years 1987 and 1988 also saw attempts to retrieve some information from the Uyak Site when 111 2 x 2 m units were excavated (Steffian 1992:147). In 1989, the Exxon Valdez Cultural Resource Program surveyed the shores of Prince William Sound, Kodiak, and the Alaska Peninsula resulting in the discovery of 262 sites (Clark 1992a:117; Mobley et al. 1990).

In the late 1980s the Tribal Council of the Larsen Bay village approached the Smithsonian Institution for return of the human remains excavated by Hrdlička at the Uyak Site (Dumond and Scott 1991). In an effort to assess the Larsen Bay claim that they are direct descendents from the earlier Koniag and Kachemak peoples, the Smithsonian undertook a study of the physical remains collected from throughout Kodiak Island, comparing prehistoric human physiology to that of the present population. Continuity between the Pre-Koniag (as Hrdlička had referred to the earlier inhabitants) and the Koniag was documented (Dumond and Scott 1991) lending support to Jordan and Knecht's (1988) arguments for continuity between the Kachemak and Koniag peoples (Dumond and Scott 1991).

Through the 1990s work on Kodiak Island proceeded with a new generation of archaeologists. In the early 1990s Yarborough (unpublished data, see Clark 1998) excavated at Larsen Bay, Reger et al. (1992) worked on Late Kachemak and Koniag sites on Shuyak Island, excavations at Malina Bay on Afognak Island began under Knecht (see Clark 1998 for personal communication), and Three Saints and its historic sections were excavated by Crowell (1997). Fitzhugh (2003a, 2004) began survey and excavation at Sitkalidak Island under the Sitkalidak Archaeological Program, generating additional data about Kodiak's Ocean Bay occupation. In 1993 'Dig Afognak', overseen by Dr. D. W. Clark, began on Afognak Island. This excavation program at Afognak Village utilizes archaeologically interested volunteers to work on the site (Afognak Native Corporation 2003).

Throughout the late 1990s to present, archaeological work has continued in the Kodiak Archipelago on Afognak Island at the Blisky site (Steffian 1997), and the Kataaq site (Woodhouse-Beyer 1997), on Sitkalidak Island at the Tanginak Springs site (Fitzhugh 2003a; 2004), and at the Rice Ridge site on Chiniak Island in Chiniak Bay, Larsen Bay, Uganik Bay (Fitzhugh 2004). The researchers from the Alutiiq Museum in Kodiak continue to conduct projects throughout the Kodiak Archipelago (Saltonstall 1997, 2011; Saltonstall and Steffian 2006; 2007; Steffian and Saltonstall 2001, 2004, 2005, Steffian et al. 2006) and by other researchers (Fitzhugh 2002, 2004; West 2011).

3.3.2 The Alaska Peninsula

Here again Hrdlička was one of the first people to make a concerted research effort. He collected Pacific Eskimo remains from Pavik at the mouth of the Naknek River (Hrdlička 1943), surveyed the tip of the Kenai Peninsula and the associated archipelago, and had his assistant Robert Heizer survey Takli Island, where evidence of pre-European occupations was discovered (Hrdlička 1944:131).

Between 1953 and 1954 Wilbur Davis and James W. Leach (1954), under the supervision of William Laughlin, conducted limited excavations at four historical villages: Savonoski at the mouth of the Savonoski River, Katmai Village in Katmai Bay, the village of Kukak in Kukak Bay, and at Kaguyak village (Davis and Leach 1954). All villages were abandoned after the eruption of Novarupta and the deposition of the Katmai Ash in 1912, with the village of Katmai buried by pumice (Davis and Leach 1954). Davis and Leach (1954) tentatively dated the initial occupation of the Katmai National Monument ca. 450 B. P. with a terminal date of 1912; we now know this is far too young as indicated by radiocarbon dates.

It was not until the 1960s that real progress was made in generating a cultural chronology for the Alaska Peninsula. Between 1963 and 1965, Gerald Clark explored Takli Island and Peninsula's Shelikof coast, excavating the Takli Island Site, the Kukak site, the Kukak Isolated Housepit Site, and the Hook Point Site (Clark 1977). Clark developed the first comprehensive cultural chronology for the Pacific coast of the Peninsula, identifying the earliest phases as the Takli Alder, followed by Takli Birch, Takli Cottonwood, Takli Beach and Kukak Mound.

Between 1960 and 1967, under University of Oregon sponsorship, Dumond conducted research in Katmai National Monument. His investigations led to the description of prehistoric cultural sequences for the Naknek drainage and the Pacific coast (Dumond 1971:3). During 1960 and 1961, excavations were undertaken at site BR-3, with limited surveys identifying three more sites near Brooks River (Sites BR-5/XMK-0011, BR 4/XMK-0038, and BR7/XMK-008). In addition, survey work at Karluk Lake relocated two sites previously identified by Hrdlička (1944). Dumond also began work at the Pavik Site (49NAK2) near King Salmon in 1961, and continuing surveys resulted in identification of sites BR8 and BR9, and 49NAK3 to 49NAK6.

Through 1963 to 1965, Dumond undertook an intensive survey project around the Brooks River and the Naknek drainage, identifying 22 new sites. His field program of 1964 focussed on the Pacific coast of Katmai, and consisted of intensive survey coverage and excavations at Kukak Bay and on Takli Island (Dumond 1971:5), thus enabling him to describe cultural chronologies for the Brooks and Naknek River drainages, and further explore the relationships between the archaeological cultures there and those of the Pacific Coast (Dumond 1971).

Dumond returned to the Brooks River drainage in 1967 and focused on excavating sites BR15, BR16 and BR20, which contained Arctic Small Tool Tradition and Thule materials (Dumond 1971:5). There was little other work in the area until excavations in 1973 and 1974 at 49NAK15 and 49NAK16 in the Naknek Drainage and five weeks of work in the Ugashik Drainage (Dumond 1971:6, 1974a).

In 1974 and 1975 work was carried out at the Ugashik Narrows and the Ugashik River was surveyed. Three sites (49-UGA-1, 49-UGA-2, 49-UGA-6) were completely excavated and some work was done at the Ugashik village site (Henn 1978). Material analysis enabled the description of Ugashik's cultural history, which appears to deviates from the Brooks and Naknek drainages, and from the Pacific Coast (Henn 1978).

In 1977, Lake Clark, Lake Telequana, Turquoise Lake, Twin Lakes, Fishtrap Lake, Lachbuna Lake, and Snipe Lake were surveyed to meet legislated compliance regulations when Lake Clark National Park was proposed (Smith and Shields 1977). The product of this survey was the discovery of 54 new sites and trails. Many sites are historic period cabins dating from the 1900s to the 1950s, although Russian graves, and prehistoric cache pits and house depressions were also located (Smith and Shields 1977). Between 1982 and 1984 Harvey Shields, a National Park Service archaeologist, worked with personnel from the University of Oregon excavating at Brooks River examining occupation seasonality and household architecture (Harritt 1988). Throughout the 1990s cultural resource management firms carried out most archaeological work in Naknek and Brooks River drainages in areas increasingly visited by tourists (Hilton 2002). In 1997, four years of work began at the Mink Island Site (XMK-030) in the Shelikof Strait, under the direction of Jeanne Schaaf, Cultural Resource Manager of Lake Clark Katmai National Park and Preserve. These excavations produced a considerable amount of cultural material and well over 100,000 faunal remains. Hilton (2002) excavated the upper, younger portion of the midden between 1997 and 1999, while Schaaf supervised the excavation of the lower, older midden sections between 1997 and 2000. Analysis of cultural and faunal material is ongoing (Eitner and Schaaf 2011; McKinney 2011; Strathe and Murray 2007; Murray et al. 2006) and Mink Island will no doubt provide a plethora of data regarding the lifeways of prehistoric coastal peoples. Research has also occurred using bivalves collected from the site to examine the Alaska Coastal Current (Hallmann et al. 2011). Stable isotope analysis was also conducted on a prehistoric burial found on Mink Island (Coltrain 2010), indicating that the majority of the inhabitants' diets were comprised of marine resources.

In addition to the work at the Mink Island site, work continued inland, undertaken by the researchers at the Leader Creek Site, the Brooks Lake Vault Toilet site (Dumond 2003, 2008), the Brooks River Cutbank Site (Bundy et al. 2005), along the King Salmon River at site UGA-052 (Hoffman et al. 2009) and at Marratuq (McClenanhan 2010).

3.3.3 Outer Cook Inlet

The first archaeological research in Cook Inlet began in the early 1930s. Frederica de Laguna excavated at Cottonwood Creek and Yukon Island as well as at sites in Prince of Wales Sound (de Laguna 1934). De Laguna established the first cultural chronology for the Kachemak Bay area (Table 3.3), and compared the cultural materials and mortuary habits of the Kachemak peoples with other archaeological groups throughout the Arctic in an attempt to identify Kachemak cultural affiliation (i.e., Eskimo versus Indian) and the relationships among Kachemak and their neighbours (de Laguna 1934).

Beginning in 1974 William and Karen Workman of the University of Alaska Anchorage carried out research in Cook Inlet and in Kachemak Bay in particular. Guided by their desire to develop a more detailed cultural chronology for the area, they excavated the Chugachik Site (SEL-033) in 1974 and again in 1977 (K. Workman 1977; W. Workman 1977), and the Cottonwood Creek Site (SEL-030) in 1974. In 1978 their excavation efforts began at the Fox Farm Site (SEL-041) on Yukon Island (Workman et al. 1980). This work led to their modification and refinement of de Laguna's (1934) original cultural chronology (W. Workman 1977, 1978, 1998:156, 2002; K. Workman

1977; Workman and Workman 1988). Lobdell (1980) sampled faunal remains from these sites, generating the data used in his discussion of Kachemak Tradition subsistence practices throughout the area. Similarly, Yesner (1977) examined the avian remains from the Chugachik Site concluding that birds were an important resource in the Chugachik economy. Concurrently, Doug Reger (1977) excavated the 49-KEN-029 site, identified by comparative analysis, as either a Kachemak II or Sub-III phase site.

In 1981 and 1982, Reger (1987) conducted investigations at the Clam Gulch Site (49-KEN-045) in an attempt to identify late prehistoric and protohistoric occupations as well as document subsistence activities. He concluded that subsistence was marine oriented but was unable to definitely identify the ethnicity of site occupants, suggesting they were Tanaina Indians with a material culture illustrating considerable Eskimo influence (Reger 1987:102).

Between 1987 and 1989, the two-component occupation of the Point West of Halibut Cove Site (49-SEL-010) was excavated (Boraas and Klein 1992). The lower component of the site contained Late Kachemak (Kachemak III and Sub-III) remains as well as late prehistoric Dena'ina Indian house remains (Boraas and Klein 1992). This site is unusual as it is one of the few with both Eskimo and a succeeding Indian occupation. Based one of the dates ca. 1000 B.P. (AD 915, WSU-3859), a narrower window between Eskimo and Indian occupation than proposed by Workman (1998). More recent research by Workman and Workman (2010) suggests that the Kachemak Bay area was abandoned by the Kachemak peoples by 1400 B. P. while the Kenai

Peninsula was abandoned by 1000 B. P. where it is closely followed by a Dena'ina occupation (Workman and Workman 2010:94).

3.4 Conclusion

The prehistoric chronology of and relationships among peoples in the Alaska Peninsula region is still unclear. A recent focus on Kodiak has improved our understanding, but considerable work is still needed to really untangle the situations, including the nature of human/ecosystem interactions. The extensive set of radiocarbon dates and methodical excavation of deeply stratified sites like Mink Island will go some way toward this.

Chapter 4

Sediments and Micromorphological Analysis

4.1 Introduction

Studies in sedimentology and pedology have demonstrated that the micro- and macroscopic examination of sediment samples enables the identification of sediment origins, whether anthropogenic or natural, and the identification of depositional processes (Courty et al. 1989; Fitzpatrick 1993; Matthews et al. 1996). Such sedimentological information provides data useful for drawing inferences about change and continuity in local environmental conditions, and it has implications for understanding both cultural and natural site formation events.

While many archaeologists currently employ micromorphological approaches, research is usually limited to examining cultural deposits in an effort to identify and characterize living floors (i.e., Boivin 2000; Courty et al. 1989; Goldberg et al. 1996; Hilton 2002; Macphail et al. 2004; Matthews et al. 1996). Few focus on the non-cultural sediments in sites or on the environmental processes that deposit and alter them, and even fewer use such data to delineate past environmental conditions (i.e., Beresford-Jones and Boreham 2009, Goldberg and Byrd 1999; Sordoillet, et al. 2007).

In the recent past, micromorphological studies in archaeology have focused on cave sites, and on sites in arid environments. The bias towards arid sites is largely because they are conducive to the preservation of anthropogenic and geomorphic sediments (Gé et al. 1993). Reports discussing micromorphological investigations at North American sites are limited and generally focus on delineating cave stratigraphy and understanding paleosols (see for example Bettis 1992; Mandel 1992; Schweger 1985). More recently, micromorphological research has been employed in coastal midden settings (Balbo et al. 2010; Beresford-Jones and Boreham 2009; Díaz and Eraso 2010; Simpson and Barrett 1996; Villagran et al. 2011).

This study is one of only two, (see Hilton 2002), to employ micromorphological analysis of archaeological sediments from a coastal Alaskan archaeological site; it is unique in its attempt to delineate non-cultural site formation processes.

4.2 History of Micromorphology Research

Studies of sediment micromorphology developed early in the 1930s as a means to assist soil scientists with pedological interpretations. One of the earlier workers in this field was Walter Kubiëna (1938, 1970). His influence is still felt today through the widespread use of Kubiëna tins for sample collection.

Following Kubiëna, Brewer (1964) created a comprehensive volume of terms for describing micromorphological features. His terminology was considered by some to be too difficult for common use (Courty et al. 1989:5) and the International Society of Soil Science (ISSS) formed a working group to generate a consensus on terminology for widespread use. The first publication from this group was the *Glossary of Soil Micromorphology* (Jongerius and Rutherford 1979). It contains 661 terms and their definitions in English, French, German, Spanish and Russian. Each definition is cross-referenced to facilitate understanding of the term, its relationship to other terms, and term origins (Jongerius and Rutherford 1979:VII). While informative, many definitions are still difficult to comprehend, often containing other terms defined or not, as the case may be, within the volume. The unwieldiness of the text is probably why it is seldom referenced in either sedimentological or archaeological studies.

Six years after the publication of the *Glossary of Soil Micromorphology,* the ISSS working group successfully created a comprehensive terminology, in the *Handbook for Soil Thin Section Description* (Bullock et al. 1985). This volume presents standardized terminology and provides explanations and examples of terms to facilitate the understanding and identification of thin section features. It was the most commonly used reference until the publication of *Guidelines for Analysis and Description of Soil and Regolith Thin Sections* (Stoops and Vepraskas 2003). That volume edits and updates the terminology to current usage. It is the primary reference for the research described here.

In archaeology, Cornwall (1958) first used micromorphological study of sediments to interpret Roman sites in Britain, but it was not until the 1980s that such studies grew in popularity. Courty et al. (1989) published a volume outlining the principles and techniques for the micromorphological study of sediments in archaeological settings to interpret site formation processes. In the 1990s, micromorphological analysis became widespread in archaeology as a method for reconstructing past environments and delineating site formation processes. The approach was and is most common in Europe (Macphail, et al. 2009; Mallol 2006; Simpson and Barrett 1996), in arid and semi-arid environments (Matthews, et al. 2006; Matthews, et al. 1997), in caves, rock shelters (Goldberg and Sherwood 2006; Jayasingha, et al. 2009; Sordoillet, et al. 2007), and at agricultural sites, to derive information about agricultural practices (Carter and Davidson 1998; Sedov et al. 2008).

4.3 Soils of the Alaska Peninsula and the Mink Island Site

To date, there is no comprehensive soil survey for the Katmai National Park and Preserve [although one is expected in 2013 (NPS 2011)], and currently the only in-depth soil study is from the Valley of Ten Thousands Smokes (Cameron 1970). However, there are brief descriptions of the sediments from across the broader Peninsula. These descriptions indicate that forested areas on the Peninsula are characterized by soils that developed on volcanic ash and ejecta (Andisols) (Natural Resources Conservation Service 1998), and that are generally classified as Typic Haplocryands and Typic Vitricryands. Cryands are Andisols that developed in cryic or pergelic soil temperature regimes. Haplocryands and Vitricryands are two great groups within the Cryand order of soils, (Shoji, et al. 1993: 84). These soils are at high latitude and altitude and have mean annual temperatures of 0°C or less. Furthermore, Haplocryands may or may not contain permafrost. They primarily support alpine tundra heath meadows and barrens, but also willow and alder at lower elevations. More detailed data regarding the soil composition, characteristics, and locations are unavailable, although at Mink Island field observations provide a general description of the site sediments and those in the local area.

The Mink Island sediments are generally silt and sand with intervening anthropogenic strata. Basal sediments are comprised of glacial till dating to the last glaciations. These are overlain by brown, yellow-brown, and red-brown silt and sand with varying gravel and pebble content. The natural strata of silt and sand are interspersed by those resulting from the human occupation of the site. These anthropogenic sediments in some levels are characterized by red ochre stained clayey silts containing fire-cracked rock, midden remains, and sediments saturated with charcoal and marine mammal blubber. There are three tephras, the KF, KE and KG tephras. The KF tephra dates between 4560 to 5090 B.P., KE between 5100 and 5300 B.P. and the KG between 3970 and 4650 B.P. (Begét 1999; Tannenbaum 1996). For additional description of the sediment profile, refer to Appendices II and III.

4.4 Excavation Methods

The Mink Island site was mapped in 1996 by Jeanne Schaaf and NPS surveyors who established separate datum markers across the site (Hilton 2002:142). The deposits discussed here are confined to the "Lower Midden" on the southwest side the island, and from the southwest side of the slope (Figure 4.1). Sixteen one by one meter units were excavated from 1998 to 2000. The units were established in relation to a permanent site datum, and unit designations were based on a north-south and east-west grid line demarcating grid zero (Figure 4.2). Units were excavated using both arbitrary five cm increments and natural stratigraphic levels identified by changes in the physical qualities of the sediments. Each level was numbered, with the exception of some very prominent occupation floors which were given descriptive designations. The depth and thickness of all stratigraphic levels were measured in relation to the height of a permanent datum. All depths noted here are centimeters below datum (cmbd).

4.5 Sediments In Thin Section and Their Attributes in Cultural and Natural Contexts

Sediments are created by physical, chemical, and biological weathering of minerals, rock, and organic material. Physical weathering includes processes such as frost wedging, thermal expansion, and exfoliation; these break down rock material into smaller particles. Chemical weathering processes include hydrolysis, dissolution, and oxidation, while biological weathering refers to the action of organisms such as plants, animals, insects, and microorganisms. Once rocks are broken down to small fragments, these are deposited in locations by mechanisms that are dependent on their environment of origin; these include continental sedimentary environments (i.e., fluvial, alluvial or lacustrine areas), transitional environments (i.e., near or at a sea or ocean), and marine environments (i.e., in the ocean). Mink Island is located in a transitional environment and the mechanisms of sediment transport and deposition are of most interest.

The internal stratigraphic structure of archaeological sediments can be broadly characterized as occupation and non-occupation strata. Occupation strata contain by-products of human activities such as micro-debitage from lithic manufacturing activities, food remains, hearth ashes, or other microscopic material remains from human actions that leave residues in the sediments (Courty et al. 1989; Gé et al. 1993; Matthews et al. 1996). Non-occupation strata are generally free of human by-products and result from natural sedimentary processes. However, both anthropogenic and natural materials are subject to the same processes subsequent to deposition, including depletion, redistribution and transformation (Gé et al. 1993). Dominant processes leading to deposition often display identifying characteristics as do the processes that follow initial deposition and that may impact strata. For instance, aeolian deposits illustrate characteristics associated with wind movement (i.e., particle sheen, deposit sorting). However, subsequent to deposition, they may develop characteristics associated with pedogenic processes (i.e.,

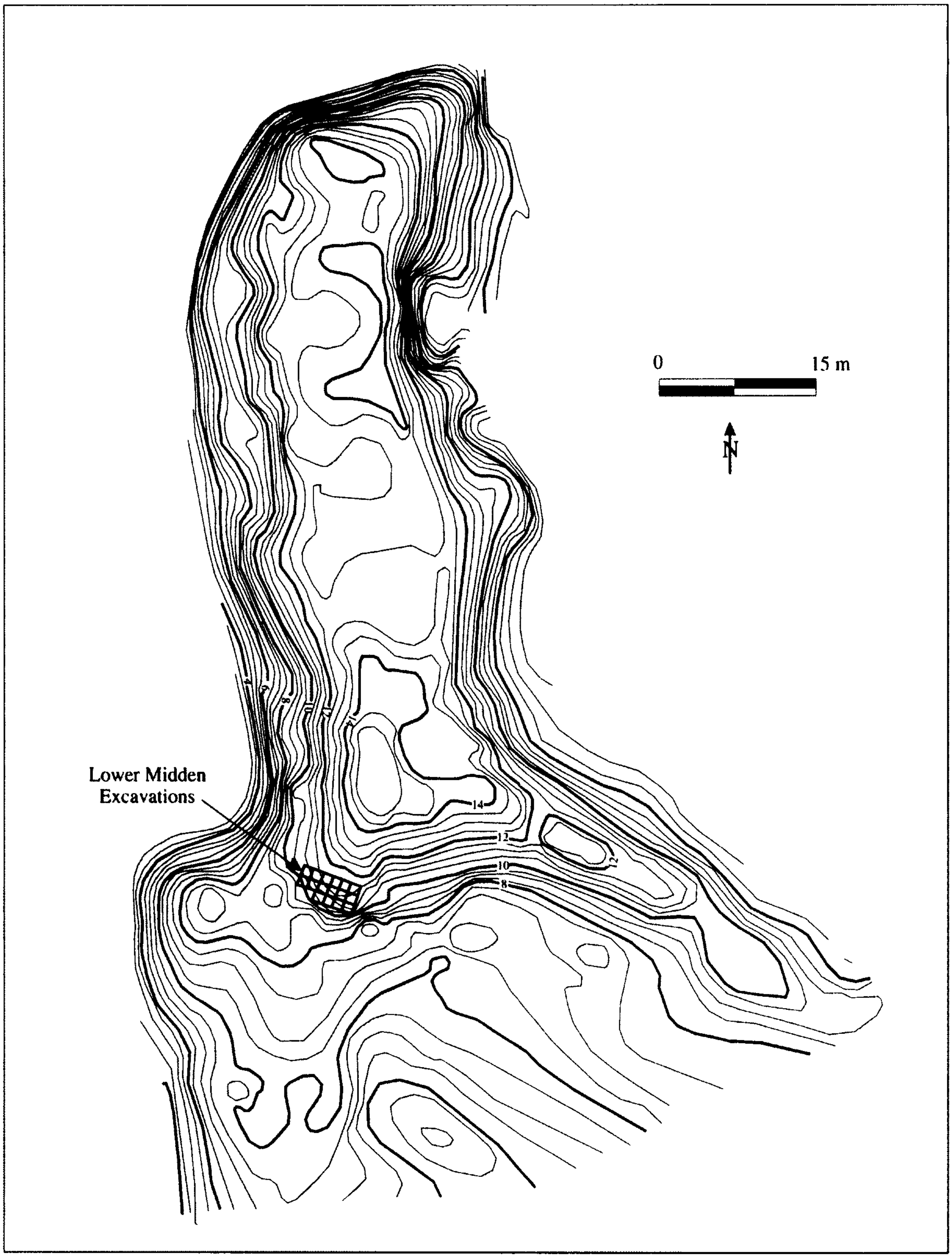


Figure 4.1 Location of lower midden excavation unites on Mink Island (after Hilton 2002:131).

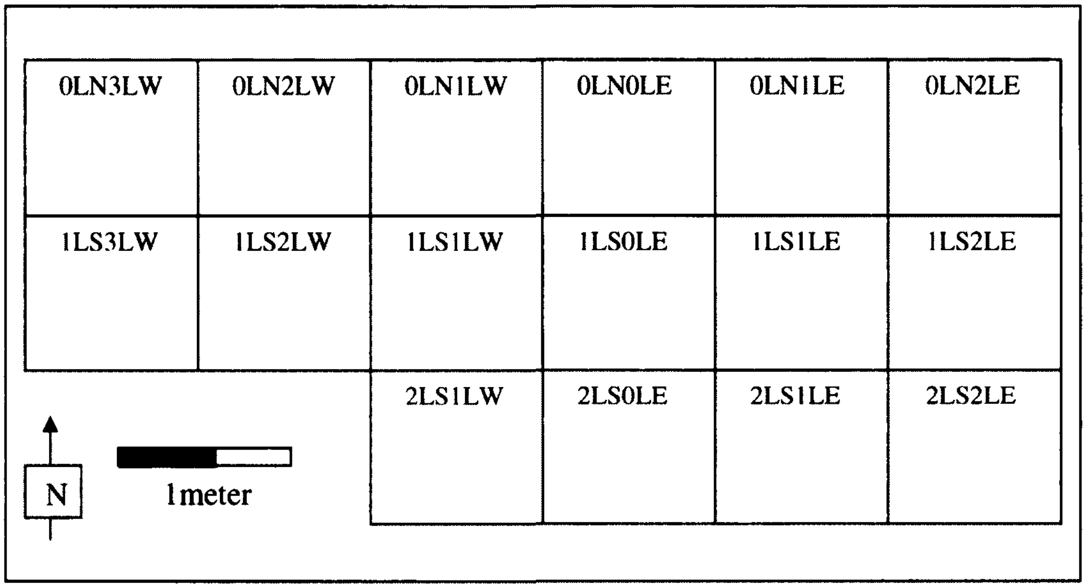


Figure 4.2 Schematic drawing of excavated units and their numbers.

bioturbation or translocation). Thus, deposits can display a palimpsest of features associated with different processes beginning to act on the sediments after their deposition. The palimpsest effect generates deposit complexity that is exacerbated in archaeological deposits by anthropogenic processes associated with human occupation(s). Because of this complexity the Mink Island sediments should be considered in terms of stable and unstable deposits, and understood with respect to the various relevant mechanisms or processes that generate sediment disturbances. Stable deposits show no evidence for erosion or deposition of sediment, while unstable deposits are undergoing erosion or deposition of sediments.

4.5.1 Biological Sediment Disturbance Mechanisms

Sediment deposits are subject to mechanical disturbances caused by biological agents including bioturbation by plants, animals, insects, and microscopic creatures such as mites (Courty et al. 1989; Fitzpatrick 1993). Plant roots mechanically disturb sediments by creating void networks as they grow through the soil; they also compact the sediments through which they travel and increase microbacteria and microorganism activities and disturbances because they create a more favorable soil environment for other microorganisms through greater aeration of the soil, which leads to better drainage and the introduction of biomass via waste products. Earthworm bioturbation leaves identifiably shaped channels lined with extraneous material brought in or excreted by the worms; earthworms are also thought to create crumb microstructures (see below) in A horizons, although secondary decomposers can remove evidence of these (Ampe and Longohr 2003:381). Similarly, insects burrowing create identifiable elliptical tubules 0.5-2 mm in diameter, with irregular boundaries of mixed organics and minerals (McCarthy et al. 1998). These tubules can also appear as elliptical structures with:

> "non-branching, bow-shaped striotubules [alternating concentrations of humus rich layers that are concavo-convex in shape and are usually associated with termite mounds and nests (Jongerius and Rutherford 1979)] that occur at an angle to bedding" (McCarthy, et al. 1998:93).

4.5.2 Physical and Chemical Disturbance Mechanisms

Non-organic mechanisms, such as wind and water, also impact sediment formation and properties. Wind action removes the fine fraction, while the coarser material moves by creep. The result is a well-sorted deposit, with well-rounded sediment grains exhibiting a dull or matted sheen or luster (Courty et al. 1989). Materials that undergo movement by water have long axes oriented downstream, shiny surfaces and rounded grains. Finer materials are moved further downstream in suspension than are coarser materials (Courty et al. 1989).

In cave deposits, materials, especially quartz, are moved via solution (water saturated with dissolved minerals) and deposited on cave floors. This fine material is often winnowed away by weathering (Courty et al. 1989). Movement of materials by solution also results in disaggregation of sediments and grains exhibit surface smoothing, similar to those affected by other kinds of water movement (Courty et al. 1989).

Solifluction is the down slope movement of water-saturated sediments. Solifluction and soliflucted environments are generally associated with seasonal freezing and thawing. Movement results from alternating frost heave and ice melt episodes (Bertran and Texier 1999:110). Macroscopic periglacial solifluction features include preferred clast orientation parallel to the slope on which the sediments are situated, internal platy structure, and folds or overturned strata (Bertran and Texier 1999:111). Under the microscope, soliflucted sediments display stratigraphy and sorting, as well as platy structures (due to ice lenses) and granular structures (Bertran and Texier 1999:112).

Overland flow of water-saturated sediments can generate massive deposits containing laminated materials. Materials may exhibit moderate sorting, and random to weakly oriented fabrics (Bertran and Texier 1999:101), although lamination can be erased by compaction and pedogenic modifications (Bertran and Texier 1999:102). Overland flow deposits can also have variable distributions, for instance, clean sands may display monic distributions, and sand and soil aggregates may display enaulic to chitonic-gefuric distributions with the fine sediment fraction forming coatings or bridges between sediment grains (Refer to Tables 4.1 and 4.2 for definitions) (Bertran and Texier 1999:103).

Colluvial movement is the gravitational movement of sediments, generally downslope. Colluvial deposits are usually poorly sorted, and contain high frequencies of coarse fractions and rock fragments (Courty et al.1989). They may also display illuviated clay which is the result of physical translocation of sediments in solution, rounded iron particles, calcareous concretions, and sharp boundaries between particles and groundmass and the presence of laminations (Courty et al. 1989).

Sediments from ocean settings also have unique characteristics. Grains modified and sorted by wave action are removed from near-shore areas and swept out to deeper water where they settle out displaying a high degree of sorting and absence of silts and clays. This process results in beach areas composed of larger, coarser fragments (Courty et al. 1989). Marine sediments may also contain diatoms of aquatic algae, mollusc fragments, and long fibrous crystals of calcium carbonate that are the remains of shell fragments, and possibly fish bones (Courty et al. 1989).

4.6 Environmental Signatures

Freeze-thaw processes such as cryoturbation and solifluction create deposits characterized by foliated, platy, cubic, angular and prismatic void structures (Van Vliet-Lanoë 1998). In the distal lobe of the soliflucted sediment, silt cappings can form on sediment grains, and if freezing is shallow, translocated clay and silt form void coatings, and undifferentiated or crystallic b-fabrics may be exhibited (Bertran and Texier 1999:112).

In addition to the character of the void structures, periglacial and temperate environments are also indicated by cappings (void infillings deposited by melted ice), slurries (which are indicative of meltwater), void coatings, clasts and rounded aggregates, gravels resulting from cryoclastic processes, as well as phosphatized and cemented calcite (Goldberg and Macphail 1990). Breakage or fragmentation of clay coatings may indicate frost heave; in a temperate environment where clay conditions allowed clay coatings to develop around sediment particles this may suggest a shift to colder conditions (McCarthy pers. comm. 2000), although fragmented clay coatings have also been attributed to bioturbation by insects, roots, and soil microorganisms (Kemp 1987b), (pedogenesis). Fragmentation of clay coatings may also provide a relative indication of the age of a deposit as coatings degenerate over time becoming increasingly assimilated into the larger sediment body (McCarthy and Plint 1999:303; Scarciglia et al. 2003:520).

Percolation of water can indicate recent deglaciation (McCarthy per. comm., 2000), while silt cappings suggest freezing temperatures (Fedoroff et al. 1990; Kemp 1985). Decalcification and precipitation of calcite at depth may also be an indicator of glacial sediments. Calcite, along with other soluble minerals such as sodium, potassium and magnesium, is dissolved in glacial meltwater and transported in solution and precipitated out when water evaporates, freezes or warms, or if pressure falls (Benn and Evans 1998:125). Re-precipitation of minerals occurs when saturated solutions reform through chemical reaction brought about by saturation, or through a complex interaction between chemical and biological factors (Courty et al. 1989:174). Pale-yellow and silty clay coatings can indicate cooler soil temperatures, while the formation of clay coatings themselves suggests temperate climates, as does the transformation of mica to smectite and/or chlorite (Velde and Church 1999:560). However, clay coatings may also indicate short-term weathering (McCarthy et al. 1998; McCarthy et al. 1999).

Silt coatings and silty-clay compound coatings may "result from translocation under more turbulent flow commonly associated with unstable or sparsely vegetated surfaces" (Kemp 1999; Kemp and Zárate 2000:8-9), generally within cold, moist environments (Kemp 1987b:380; McCarthy and Plint 1999:306). Conversely, dark red clay coatings and calcite nodules are associated with warmer, either arid or tropical, climates (McCarthy et al. 1998).

Increased frost action and therefore, freezing temperatures, are indicated by coarse infillings, rounded microaggregates (Fedoroff et al. 1990), and intercalations. Intercalations are "elongate, undulating pedofeatures unrelated to natural surfaces and not consisting of single crystals or crystal intergrowths" (Stoops and Vepraskas 2003:121). In addition to a cold climate association, intercalations indicate poorly drained soils (McCarthy et al.1998).

Paleosols are good indicators of past climatic/environmental conditions. Soil development requires surface vegetation; soil production begins through the incorporation of organics, weathering of materials and the movement of materials within the newly formed soil (Kemp 1985). Surface crusts, subsurface compaction, coarse moderately sorted coatings or infillings cross-juxtaposed on older clay coatings may develop with increased aridity. Mineral sorting also occurs with drier conditions, shrink-swell conditions, and decreased bioturbation (Fedoroff et al. 1990).

4.7 Methods

4.7.1 Sampling and Processing

Here, tin cans were used to extract sediment samples from the exposed profile in two vertical lines in the western and eastern parts of the site (Figures 4.3 to 4.6). Prior to sample collection, a hole is cut in the bottom of each clean can, and cut-to-fit foam is inserted into the can to cover the hole but still allow air to enter. After the sediment was extracted, additional foam was used to cover the open end and the cans were sealed for transport.

The samples from the western profile capture sediments from the upper levels and the eastern ones from the lower levels. Can placement was mapped using an electronic transit/total station. An arrow on each can indicated its position in the profile. Can placement overlapped so that a number of sample boundaries were collected. The goal was to obtain a continuous, representative block sample of the profile. Collection of stratal boundaries is important as these often contain evidence of changes in depositional processes or hiatuses (van der Meer et al. 1997).

In the lab, the foam was removed from the larger end of each can, allowing additional air flow, and the sediments within were left to air dry for two weeks, then shipped to Spectrum Petrographics in Vancouver, Washington, who prepared thin-sections from the canned sediments. The sediments were fully dried using acetone replacement. The samples were placed under vacuum above a tray of acetone; the

Figure 4.3 Photograph of can placement in the western portion of the profile. Note the material used to cover the holes in the bottoms of the can appears as an intact can, and the can number refers to the slide number.

Figure 4.4 Photograph of can placement in the eastern profile of the site.

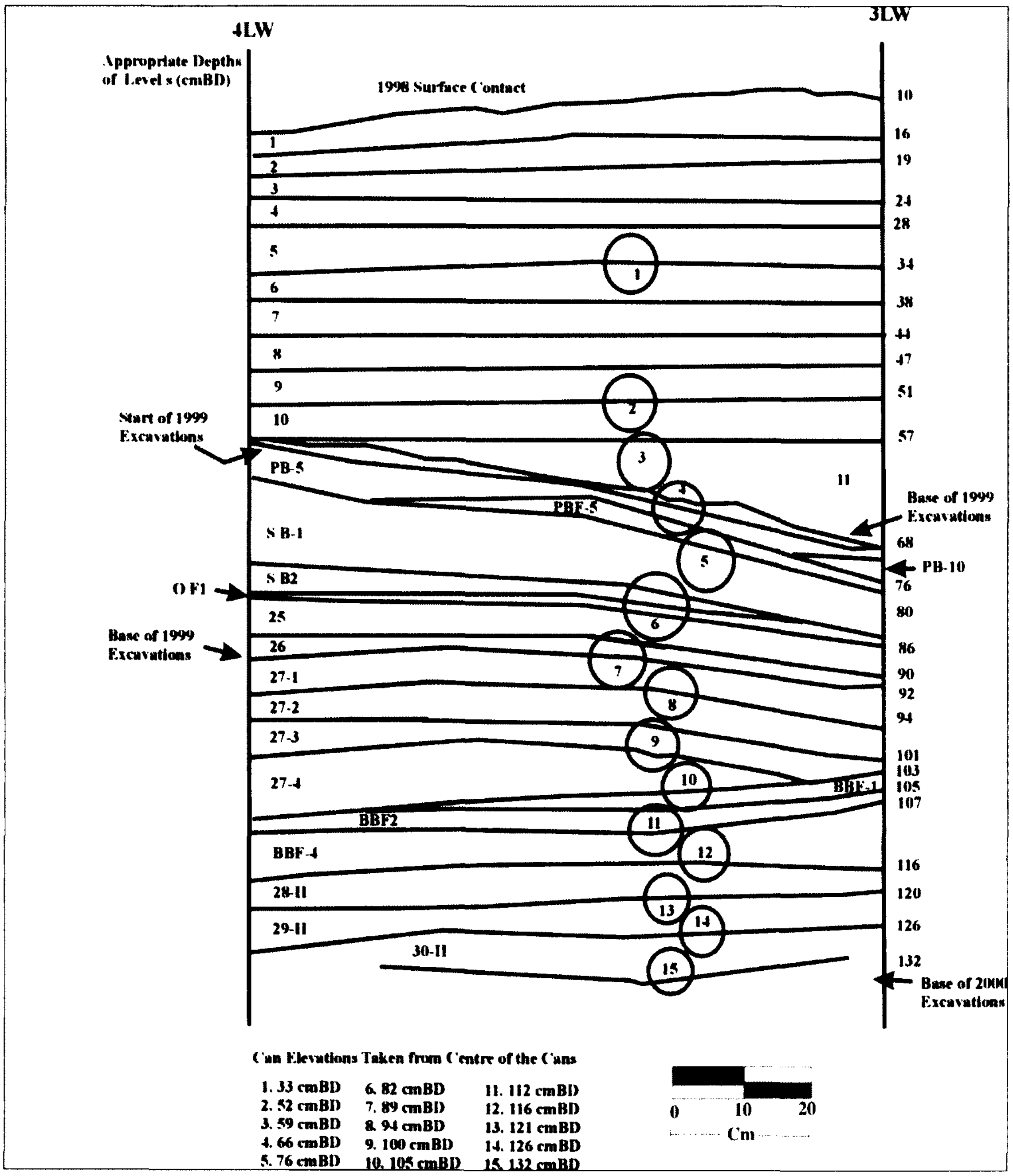


Figure 4.5 Schematic illustration of can placement in the western portion of the site profile.

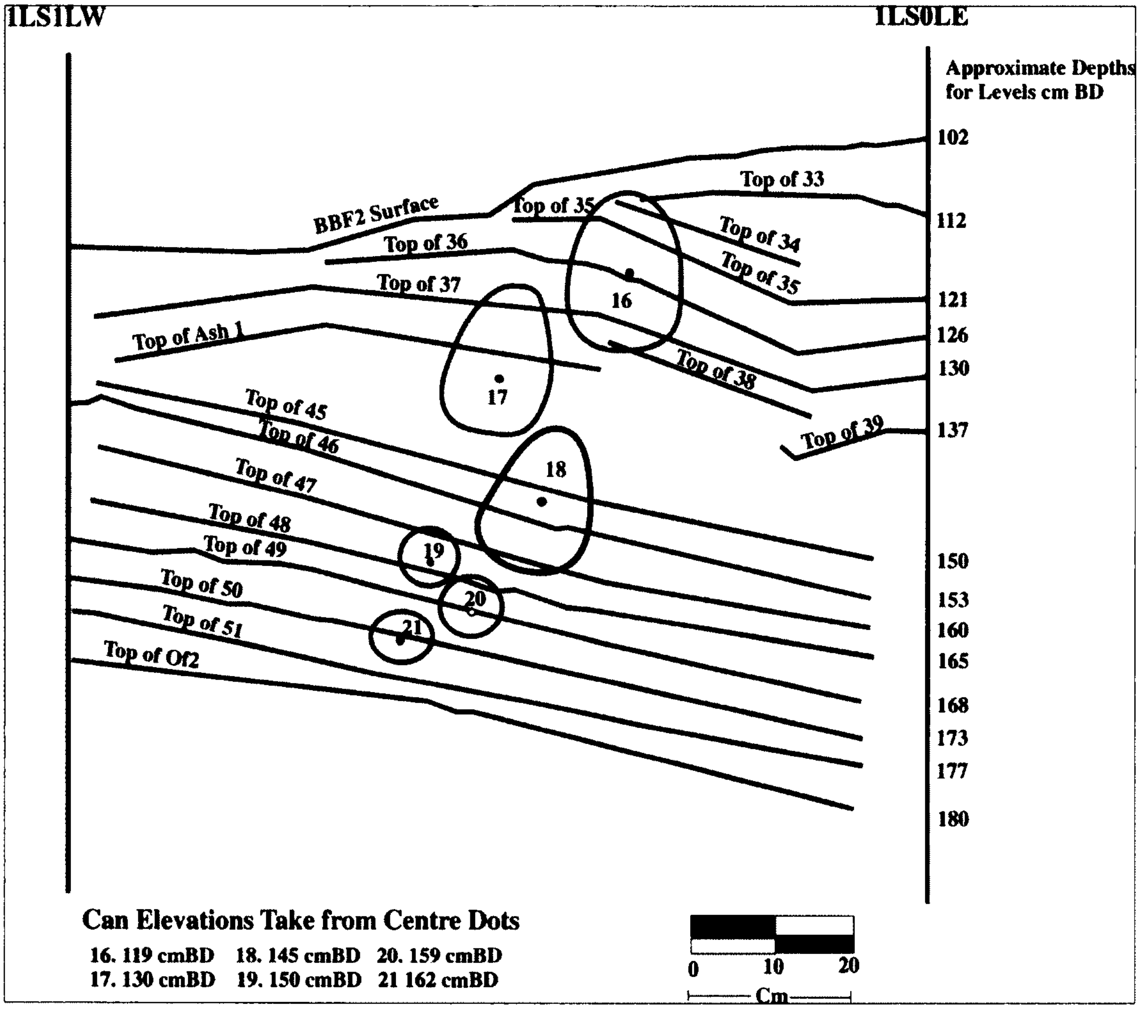
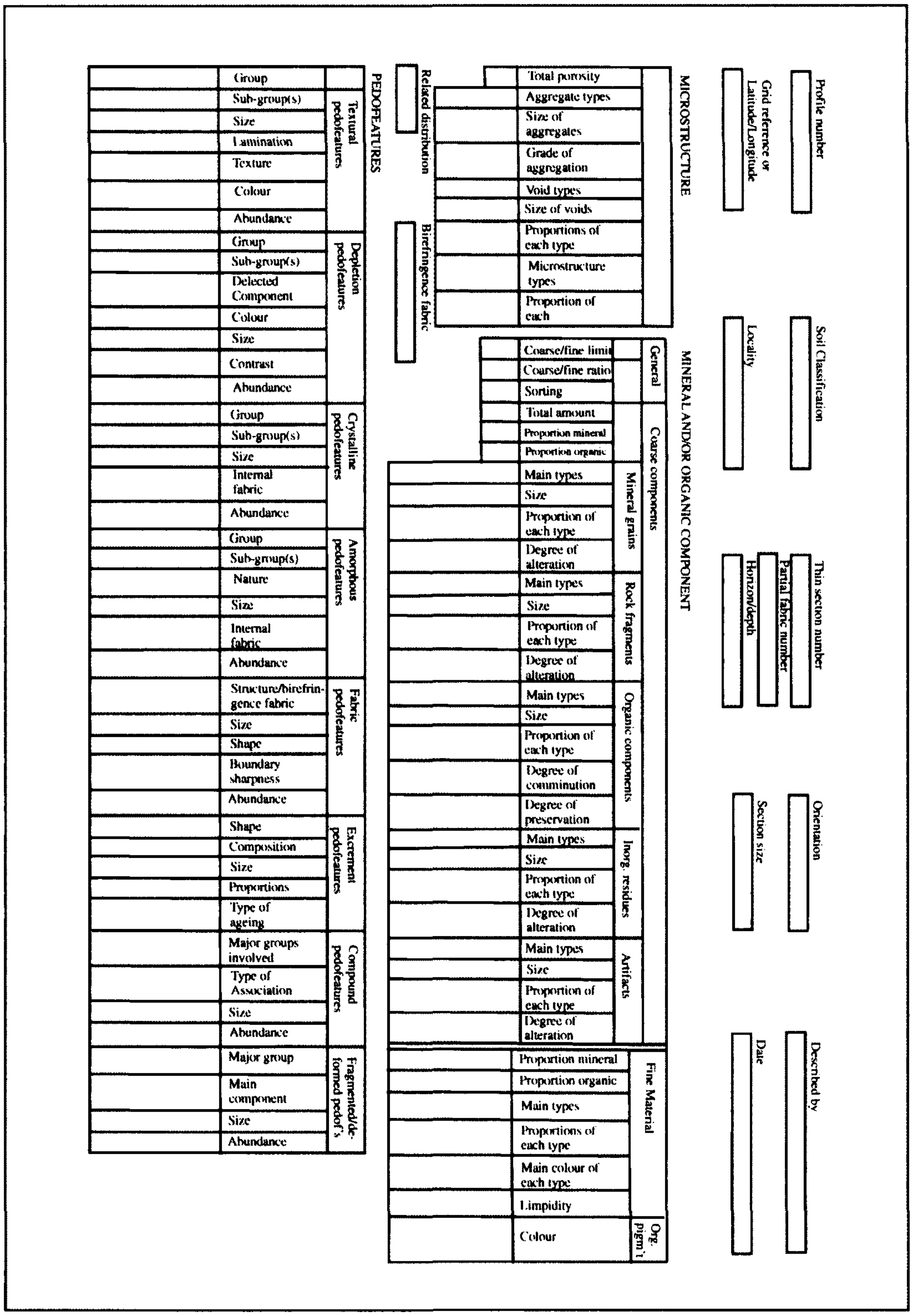


Figure 4.6 Schematic illustration of can placement in the eastern portion of the site profile.

evaporating pore waters are replaced by acetone gases. The samples were then saturated with epoxy through capillary action within the vacuum. Once saturated, samples were cured (hardened), removed from the cans, and cut into blocks measuring 27 millimeters (mm) by 57 mm. All blocks except those from samples 16, 17, and 18, were cut center and perpendicular to the can, thus capturing the complete portion of the profile contained. Sections were removed from each block, affixed to a glass slide and ground to a standard thickness of 30 μm. Permanent marks were made on each slide to identify what was the the slide's orientation, i.e. which was the upper strata and which was the lower on the slide.

Twenty one can samples were collected, but samples 16, 17, and 18 were collected in cans larger than those used for the remaining samples. The sediments in these samples were not completely permeated by epoxy and useable slides were unobtainable, leaving a total of 18 samples for analysis. These were examined macroscopically and microscopically using a Nikon Type 104 petrographic microscope with an HFX-11 camera attachment. Photographs of macro- and microscopic features were taken and observation procedures followed those developed by Bullock et al. (1985). These were recorded on prepared sheets (see Figure 4.7). This enabled systematic description of thin section features, estimates of numbers of features, and detailed qualitative descriptions.

Examination of slides using low power magnifications (five and ten times) enabled identification of macroscopic features, while examination at higher magnifications (ca. 50 X) enabled identification of macroscopic features, while higher magnifications, between 50 and 200 X, examined microscopic features. Plane-polarized light and cross-polarized light were used to identify different minerals. Appendix I contains photographs of each slide in its entirety, and Appendix II the general observations recorded during slide examination. For a description of the sediments from within the site, as recorded by fieldworkers during excavations, refer to Appendix III.



Profile number
Grid reference or Latitude/Longitude
Soil Classification
Locality
Thin section number
Partial fabric number
Horizon/depth
Orientation
Section size
Described by
Date

MICROSTRUCTURE
Total porosity
Aggregate types
Size of aggregates
Grade of aggregation
Void types
Size of voids
Proportions of each type
Microstructure types
Proportion of each
Related distribution
Birefringence fabric

MINERAL AND/OR ORGANIC COMPONENT
General: Coarse/fine limit; Coarse/fine ratio; Sorting
Coarse components: Total amount; Proportion mineral; Proportion organic
Mineral grains: Main types; Size; Proportion of each type; Degree of alteration
Rock fragments: Main types; Size; Proportion of each type; Degree of alteration
Organic components: Main types; Size; Proportion of each type; Degree of comminution; Degree of preservation
Inorg. residues: Main types; Size; Proportion of each type; Degree of alteration
Artifacts: Main types; Size; Proportion of each type; Degree of alteration
Fine Material: Proportion mineral; Proportion organic; Main types; Proportions of each type; Main colour of each type; Limpidity
Org. pigm't: Colour

PEDOFEATURES
Textural pedofeatures: Group; Sub-group(s); Size; Lamination; Texture; Colour; Abundance
Depletion pedofeatures: Group; Sub-group(s); Delected Component; Colour; Size; Contrast; Abundance
Crystalline pedofeatures: Group; Sub-group(s); Size; Internal fabric; Abundance
Amorphous pedofeatures: Group; Sub-group(s); Nature; Size; Internal fabric; Abundance
Fabric pedofeatures: Structure/birefringence fabric; Size; Shape; Boundary sharpness; Abundance
Excrement pedofeatures: Shape; Composition; Size; Proportions; Type of ageing
Compound pedofeatures: Major groups involved; Type of Association; Size; Abundance
Fragmented/deformed pedof's: Major group; Main component; Size; Abundance

Figure 4.7 Micromorphological data entry sheet (following Bullock et al. 1985).

4.8 Thin Section Terminology

For the microscopic analysis of the thin sections a number of different properties were considered. These included the ground mass, mineral and organic types, artifact presence (such as bone or charcoal) and pedofeatures. While there are many kinds of fabric patterns (i.e. the relationship between the coarse and fine particles, referred to as c/f patterns), pedofeatures, void types, and microstructures types, those most commonly observed in the sediments are defined below.

Soil fabric is "the total organization of a soil, expressed by the spatial arrangements of the soil constituents...their shape, size, and frequency..." (Stoops and Vepraskas 2003:34 after Bullock et al. 1985). An important component of soil fabric analysis is the identification of the types of related patterns displayed, with the c/f (coarse/fine)-related distribution a primary observation. The c/f-distribution describes the distribution of coarse and fine material and associated voids or "the distribution of individual fabric units in relation to smaller fabric units and associated pores" (Stoops and Vepraskas 2003:42, after Stoops and Jongerius 1975). The different c/f-distribution patterns observed within the sediments include monic, gefuric, chitonic, enaulic, and porphyric and are described in Table 4.1.

Pedofeatures are "discrete fabric units present in soil material that are recognizable from adjacent material by a difference in concentration in one or more components or by a difference in internal structure" (Stoops and Vepraskas 2003:101). Examples of pedofeatures include coatings, calcite nodules, soil fauna excrement, and passage features created by soil fauna (Stoops and Vepraskas 2003:101). The different types of pedofeatures observed within the sediments are described in Table 4.2.

Table 4.1 C/f-Distribution Patterns (Bullock et al. 1985; Stoops and Vepraskas 2003).

C/F-Distribution	Definition
Monic	-fabric units are only one grain, are larger or smaller than the associated pore
Gefuric	-larger grains and aggregates linked by braces or bridges of finer material
Chitonic	-aggregates and larger grains that are covered by and surrounded by a fabric of smaller grains such as silt or clay
Enaulic	-aggregates of fine-grained particles within the interstitial spaces of between larger grains
Porphyric	-larger grains occur in a groundmass of finer-grained materials

Table 4.2 Pedofeature Types (Bullock et al. 1985; Stoops and Vepraskas 2003).

Pedofeature	Definition
Coatings	-intrusive pedofeatures coating the natural surface of voids grain, or aggregates
Nodules	-"equidimensional pedofeatures that are not related to natural surfaces or voids and" are not comprised of crystals or crystal growths
Infillings	-voids that are filled or partly filled by soil or fraction of it
Papule	-nodules comprised of clay. They may have sharp boundaries and are prolate, equant or rounded in shape, or they may have diffuse boundaries indicative of *in situ* development

Microstructure refers to the relationship between the aggregates and the inter- or intrapedal voids (Stoops and Vepraskas 2003:57). It is the size, shape and arrangement of particles and voids in aggregated and non-aggregated material, and the size, shape, and arrangement of the aggregates (Bullock et al. 1985:18; Stoops and Vepraskas 2003:57). The most common microstructures observed in the Mink Island sediments described in Table 4.3.

"*Voids* are the spaces between, within, or across aggregates of sediment, and within non-aggregated material such as grains (Bullock et al. 1985:43; Stoops and Vepraskas 2003:63). Classification of void type is based on void orientation (parallel, perpendicular), and relative size, and shape (Bullock et al. 1985:43; Stoops and

Vepraskas 2003:63-66). Table 4.4 describes the different void types commonly observed in sediment profiles.

Table 4.3 Microstructure Types (Bullock et al. 1985; Stoops and Vepraskas 2003).

Microstructure	Descriptions
Spongy	-where the continuity of the solid material is broken by many voids that are often interconnected;
Crumb	-rounded, rugose aggregates that are often comprised of welded granules
Granular	-compound packing voids separate granules that contain few voids
Subangular blocky	-solid material is divided into subangular aggregates by planar voids, and aggregates may have vughs and channels within them
Angular blocky	-where aggregates have angular edges and the few voids present are planar
Complex	-a mixture of two or more types, which is often described using a combination of structure terms

Table 4.4 Descriptions of Different Void Types (Bullock et al. 1985; Stoops and Vepraskas 2003).

Void	Descriptions
Packing	-voids with unaccommodating faces, equant to elongated, interconnected; of these there are simple packing, compound packing, and complex packing voids
Vesicles	-large voids with smooth walls, equant, prolate, or oblate, usually horizontal distribution
Channels	-tubular smooth walled, cylindrical or arched cross section, possibly root channels
Chamber	-equidimensional smooth-walled interconnected by channels
Vughs	-equidimensional, irregular, smooth or rough walls, not usually interconnected
Planes	-planar, flat, accommodating or not, smooth or rough

Organic components are the remains of roots, organic excrements, plant residues and/or organic materials deposited by human occupation. Within the Mink Island sediments, plant material is observed in thin section. Animal residues observed in the Mink Island sediments were restricted to bone fragments associated with the human occupation floors. The primary organic components observed were tissue residues and organic fine material (Tables 4.5 and 4.6).

Table 4.5 Descriptions of Organic Residues (Bullock et al. 1985; Stoops and Vepraskas 2003).

Plant Residue	**Descriptions**
Parenchymatic tissue	-more or less equant thin-walled cells, cell lumen usually empty except for plasma on cell walls
Lignified tissue	-elongated, thick-walled originally empty cells
Phlobaphene-containing tissue	-equant to oblate cells with phlobaphenes in the cell lumen, phlobaphenes have high chroma yellowish, brownish or reddish colors

Table 4.6 Descriptions of Organic Fine Materials (Stoops and Vepraskas 2003).

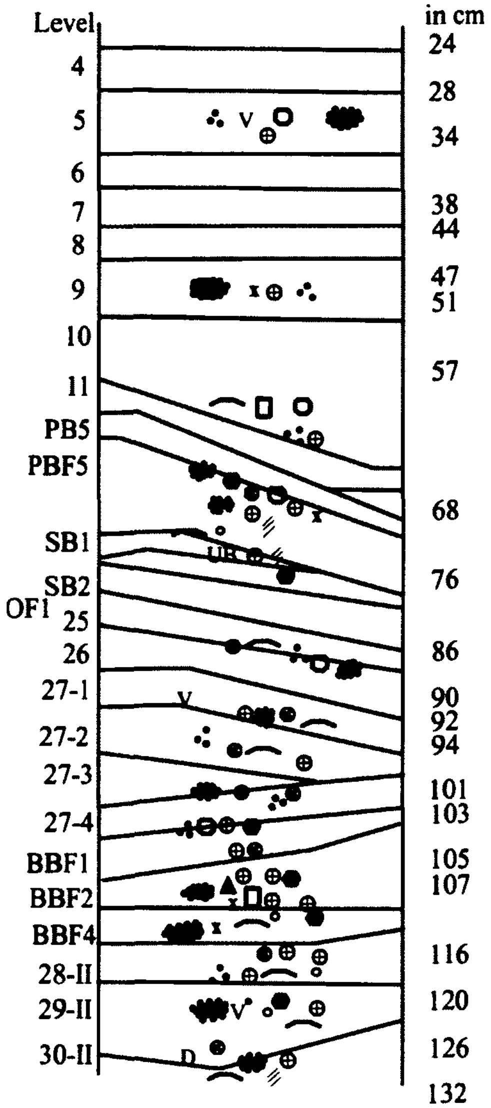
Organic fine material	**Description**
Cells and cell residues	-organic fragments with recognizable cells, group includes spores and pollen grains
Amorphous organic-monomorphic	-"amorphous organic fine material of uniform colloidal texture with <5% inclusion of coarser organic elements" (Stoops and Vepraskas 2003:89)
Amorphous organic-polymorphic	-"amorphous organic fine material with >5% coarser organic elements...forming a discontinuous mass of polymorphic elements of different color and density." (Stoops and Vepraskas 2003:89)

4.9 Thin Section Analysis

Below the various features in the Mink Island profile are described and interpreted. Figures 4.8 and 4.9 illustrate estimates of abundance of micromorphological features and their microstratigraphic relationship. Examples of key micromorphological features are illustrated in Figures 4.10 and 4.11.

4.9.1 Microstructure and Fabric

Most components consist of spongy or crumbly microstructures with subangular blocky or angular blocky structures. Peds are between two and ten mm and surfaces range from accommodating to unaccommodating. Complex packing and chamber voids, with a limited number vughs lacking orientation and ranging in size from two to 200 microns (μm) were observed. Some layers exhibit ultra-fine to coarse voids and complex and crumbly microstructures, subangular blocky structures, and channel and crumb



Slide Number (Levels)	Microstructure	B-fabric	Void coatings	Grain coatings/Cappings	Papules	Fe-Coatings	Fe-Nodules	Organics	Organic Staining
1 (5)	S/C	ST/S	•	•	"	"	•••	•	"
2 (9)	S	ST/S	"	•	"	"	•••	•••	"
3(10)	ST/S	C/S	"	•	"	"	••	•	••
4 (11/PB5)	S/C	ST/S	"	"	•	"	••	••••	"
5 (PBF5/SB1)	C/S	UB	"	•	•	••	•••	•••	"
6 (SB2/25)	C/S	ST	"	•	"	••	••	•••	"
7 (27-1)	S	ST	"	•	"	"	••	•	"
8 (27-2)	S	S	"	••	"	"	••	•••	••
9 (27-3)	S	S	•	"	•	"	••	••	"
10 (27-4/BBF1)	S/C	ST	"	••	"	"	••	••••	"
11 (BBF2/4)	C/G/S	S	•	•	•	"	••	••••	"
12 (BBF4 fill/top 28-II)	S	ST	"	••	••	•	••	••	•
13 (29-IIsurface/fill)	C/S	S	••	••••	•	"	••••	••	"
14 (29-II fill)	S/C	ST	••	••	•	"	••••	••	"
15 (30-II)	S	D	••	••	"	••	••	••	"

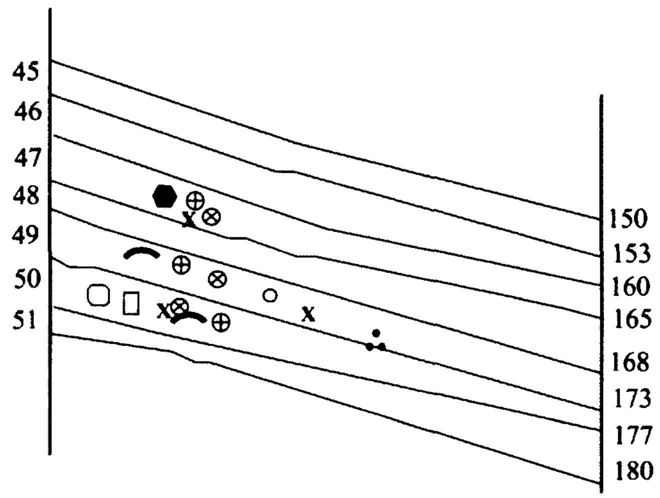
Microfeatures
- " Not detected
- • Rare (<0.2%)
- •• Very few (0.2-2.0%)
- ••• Few (>2-5%)
- •••• Common (>5%)

Microstructure
- B Blocky
- C Crumbly
- S Spongy
- G Granular

B-fabric
- S Speckled
- ST Stipple Speckled b-fabric
- UD Undiffrentiated

Micro features
- □ Blocky Structure
- ● Crumbly Structure
- Spongy Structure
- ▲ Granular Structure
- ∴ Speckled b-fabric
- x Stipple speckled b-fabric
- UB Undifferentiated b-fabric
- ⊕ Organic Tissue (plant cells/bone)
- O Organic Staining
- V Void Coatings
- Redoximorphic Features
- ● Nodules
- Aggregate or grain coating
- O Clay Papule

Figure 4.8 Detailed microstratigraphic log for the profile exposed in the western portion of the Mink Island Site.



Slide (Levels)	Microstructure	B-fabric	Void Coatings	Grain coatings/ Cappings	Papules	Fe-Coatings	Fe-Nodules	Organics	Organic Staining
19 (47)	S/C	S	"	"	"	"	•••	•••	"
20 (48/49)	S/C	S	"	•	•	•	•••	•••	"
21 (49/50)	B	S	"	"	•	"	••	•••	"

Legend

Microfeatures
- " Not detected
- • Rare (<0.2%)
- • • Very few (0.2-2.0%)
- • • • Few (>2-5%)
- • • • • Common (>5%)

Microstructure
- B Blocky
- C Crumbly
- S Spongy
- G Granular

B-fabric
- S Speckled
- ST Stipple Speckled b-fabric
- UD Undiffrentiated

Micro features
- □ Blocky Structure
- ● Crumbly Structure
- Spongy Structure
- ▲ Granular Structure
- ∴ Speckled b-fabric
- X Stipple speckled b-fabric
- UB Undifferentiated b-fabric
- ⊕ Organic Tissue (plant cells/bone)
- O Organic Staining
- V Void Coatings
- Redoximorphic Features
- ● Nodules
- Aggregate or grain coating
- O Clay Papule

Figure 4.9 Detailed microstratigraphic log for the profile exposed in the eastern portion of the Mink Island Site.

structures with undulating surfaces. In several sections, voids are narrow due to sediment compaction due to overburden pressure.

The coarse fraction from throughout the profile is comprised primarily of plagioclase feldspar, quartz, biotite, hornblende, and fragments of schist, sandstone, and mafic rock particles. Several sections contain rounded and subrounded feldspars, quartz and rock fragments. All minerals exhibit some surficial weathering, with the most extensively weathered minerals located in the basal portion of the deposit.

Fine-grained sediments, those that comprise the matrix, are largely mineral material with minor quantities of organics. Distinguishing mineral types is difficult as there is a considerable amount of red-brown staining on the fine-grained sediments throughout the profile. This staining is likely the result of translocation of ferrous material in solution downward (Payton and Usai 1995). Despite the extensive staining feldspars, primarily plagioclase feldspars, and quartz minerals were observed in some sections.

The fine-grained sediments primarily exhibit stipple-specked b-fabric. Stipple specked b-fabrics are characterized by "individual isolated speckles and mosaic speckled fabrics, where the birefringent speckles are in contact with each other" (Bullock et al. 1985:91; McCarthy 2002:166; McCarthy and Plint 1999:297), with fine matrix containing randomly arranged equidimensional or prolate speckles of optically oriented clay (Bullock et al. 1985:91; McCarthy and Plint 1999:297).

The relationship between the coarse and fine particles throughout the deposit is primarily chitonic, with instances of close porphyric, enaulic, and gefuric distribution.

Characteristics of chitonic distributions are coarse grains surrounding smaller ones, porphyric where larger gains are embedded within a matrix of finer grained material and there are few interstitial spaces, and gefuric distributions are characterized by coarse grains attached by bridges of fine grains (Bullock et al. 1985:36; Stoops and Vepraskas 2003:42). Enaulic distributions are comprised of large grains with aggregates of small ones present within interstitial space; the smaller aggregates do not completely fill these(Bullock et al. 1985:36; Stoops and Vepraskas 2003:42).

4.9.2 Interpretation of Microstructure

The red-brown staining and material within and on the groundmass is the result of ferrihydrite staining, and the presence of manganese and highly humified organic matter (Payton and Usai 1995). The staining occurs as organics release ferrous material in the form of ferrhydrite that translocates downward through the profile (Birkeland 1984:105). Incorporation of manganese and organics into the groundmass can result from downward migration of these minerals and particles while in solution, with subsequent incorporation into the groundmass via redoximorphic processes and pedogensis (Lindbo et al. 2009). Red colored matrices (Figure 4.10 A, Level SB-II, 69-78 cmbs, Slide 6) in association with amorphous iron nodules throughout the profile suggest warmer, more humid sediment conditions (Birkeland 1984; Bullock and Murphy 1979). However, given the geographic location of the site (in the subarctic), the red matrices probably indicate Fe oxidation, or redoximorphic processes associated with seasonal wetting of the site (allowing downward migration) and drying (oxidation) of the sediments. Translocation (movement) of particles and minerals within the sediment profile is also suggested by the predominance of stipple speckled b-fabrics in most samples (Bullock et al. 1985; Hussein and Adey 1998; McCarthy and Plint 1999; Simpson and Barrett 1996).

It is frequently assumed that red stained sediments are due to red ochre deposition by site occupants but there many natural processes that can cause soil oxidization which looks similar. To establish the presence of anthropogenically deposited red ochre in non-cultural levels requires chemical analysis and archaeologists should exercise caution in interpretation, especially of non-cultural levels. In this instance it is very unlikely that the red matrices in these non-cultural levels are a product of the red ochre (hematite) stained marine mammal blubber deposited into the site. None of the levels containing red matrices are located directly below ochre levels (see Hilton 2002:229 for examples of red ochre staining). Moreover, previous research suggests that the ochre soaked marine mammal blubber serves as a moisture barrier causing standing water and discoloration (Hilton 2002:230) and possibly preventing the movement of ochre through sediments.

Feldspars and silt are common throughout the profile, but there is an overall paucity of clay. Feldspars weather rather rapidly to clay and the presence of feldspars, in conjunction with silt particles suggests that after sediment deposition, chemical and physical weathering was not particularly extensive. This is surprising as coastal deposits are subject to considerable chemical weathering, and feldspars are susceptible to this and to alteration during diagenesis. The feldspars and quartz may have originated from a nearby deposit or there may have been rapid burial and subsequent protection from water (Mücher and Morozova 1981:174). More likely, periglacial conditions (freezing seasonal

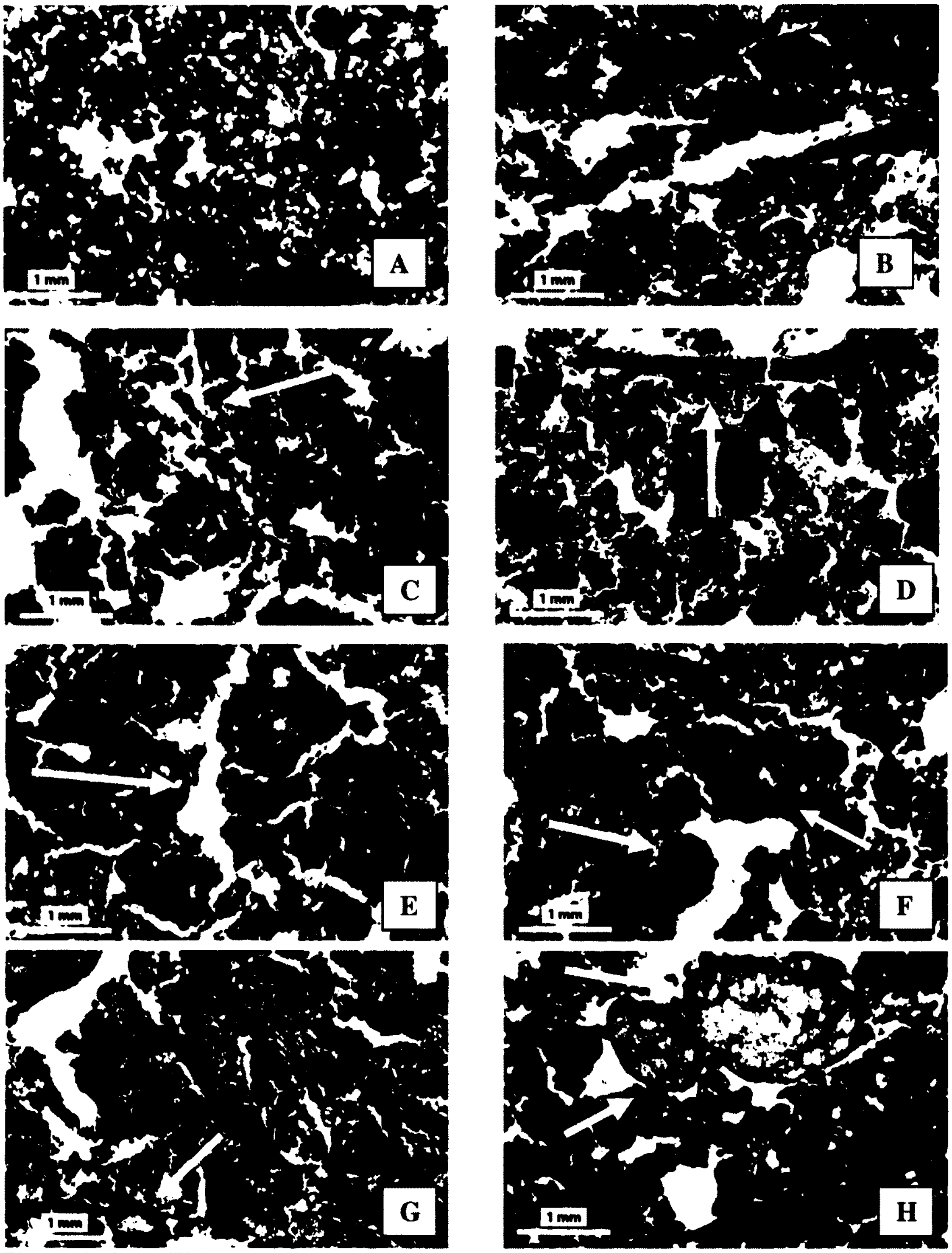


Figure 4.10 (A) Thin section photo showing reddened sediments caused by redoximorphic environment; (B) Opaque organic material associated with human occupation (arrow); (C) Fractured bone material associated with human occupation (arrow); (D) Bone fragment; (E) Silty void coatings (arrow); (F) Diffuse silty grain and void coatings (arrow); (G) Rounded silty coating on mineral grain (arrow); (H) Rounded silty coatings on mineral grains (arrows).

temperatures), and sediment compaction caused by human occupation, together limited chemical weathering and clay production in some sections of the profile (Birkeland 1984:286; Nesbitt et al. 1997).

The presence of redoximorphic (i.e., impregnative features on grains), and oxidizing features in some sections of the profile indicate that the amount of translocation varied throughout the sediment column. This also suggests that when water inputs did occur saturation was of a short duration and that the environment was largely oxidizing (Lindbo et al. 2009).

4.9.3 Biological Features

Root traces and channels are not extensive. Those present are one millimeter or less in diameter, and they are vertically or sub-horizontally oriented. The predominant matrix is a dark brown and opaque material and brown ferrihydrite and /or colloidal organic matter (Fitzpatrick 1993:98), although there are several other types of organic matter present. These organics occur as: (1) large fragments (0.5-5mm) of opaque material with cellular structure (lignified); (2) fragments (0.5-1 mm) of opaque material with cellular structure and phlobaphene tissue, red-brown in color; (3) fragments (1-5mm) of bone material, generally associated with sections identified as occupation levels; (4) small (0.5-4 mm) opaque; and (5) fine opaque particles.

Pseudomorphic and lignified cellular materials are present. Pseudomorphic material has had the organics replaced by iron oxides, suggesting oxidizing conditions subsequent to burial of the plant material (Fitzpatrick 1993:83). Lignified tissue is thick walled cellular material, with prolate cell structure, and a lack of cellular content. This type of tissue commonly represents stalks, leaves, and sometimes charcoal (Bullock et al. 1985:18). Living floors contain a considerable amount of decayed opaque organic materials, stained sediments, as well as fragments of cellular plant material and bone pieces (Figure 4.10 B, Level SB-1, 66-77 cmbs, Slide 5; 4.10 C, Level 27-4, 102-107cmbs, Slide 10; 4.10 D, Level 10, 48-55 cmbs, Slide 3).

4.9.4 Interpretation of Biological Features

Cellular organic material is common throughout the deposit. These fragments can occur as soluable organic complexes that move through the profile (Brewer 1972:89). The movement of this kind of organic material can cause the brown staining of the fine-grained material found in parts of the deposit. The greatest densities of organic particles are associated with sections identified in the field as human occupation floors. Post-abandonment, there could have been considerable biological activity in the occupation floors.

While fecal matter, and the tubular structures associated with micro-faunal activity are both absent, this absence can suggest high biological activity leading to the in-mixing of fecal material with other organics (Bouma et al. 1990:260; Brewer 1972:89). Root channels, which are also absent, maybe absent due to similar processes, and as a result of human compaction.

The decomposed nature of organic materials indicates that some biological and chemical reactions occurred prior to burial (Simpson and Barrett 1996:549), perhaps through pedogenesis (Simpson and Barrett 1996:549). The absence of evidence for faunal activity and the blackened plant fragments suggest fungal and bacterial activity which can also lead to disintegration of fecal matter, however, it also suggests there were alternating episodes of sediment wetting and drying (Bouma et al. 1990:260).

4.9.5 Textural Pedofeatures-Void and Grain Coatings and Papules

Both grain and void coating features are common throughout the profile. The most prevalent types of coating are void hypo-coatings of silt and grain coatings of silt. All coatings are comprised of red-brown silt particles without laminar structures [Figures 4.10 €, Level 29-II 124-131 cmbs, Slide 14; Figure 4.10 (F), Level 30-II, 128-134 cmbs, Slide 15]. Several grain coatings have sharp rounded boundaries [Figures 4.10 (G), Level 50 and 51, 159-166 cmbs, Slide 21; Figure 4.10 (H), Level 27-2, 90-95 cmbs, Slide 8) although most of both the void and the grain coatings have diffuse surfaces, indicative of *in situ* development. All coatings observed are relatively thin.

Papules are small, subrounded, clay-rich pellets, similar to typic ferruginous nodules. They possess undifferentiated internal fabrics, and sharp external boundaries, and are red-brown in color. They are commonly associated with voids and are generally rare in the profile. Papules are problematic as they can be the result of repeated swelling and shrinking of broken clay coatings that are incorporated into the groundmass. They are developed elsewhere during soil formation and are subsequently redeposited in younger sediments via low-energy erosion and short distance colluvial movement (Brewer 1964; Durn 2003:95; McCarthy and Plint 1998:389; Mücher and Morozova 1981:154). Rounded papules may also be produced by the biological reworking of clay coatings [Figure 4.11(A), Level 47, 159-160cmbs, Slide 19] or by cryoturbation. Clay pedofeatures with diffuse borders that are embedded in the matrix (Figure 4.11 B Level 27-3, 95-102 cmbs, Slide 9) suggest *in situ* development (McCarthy and Plint 1998:389; Tarnocai and Smith 1989:153).

4.9.6 Interpretation of Textual Pedofeatures

Coatings develop during translocation when water enters the sediment column and silt becomes suspended. Gravity causes the suspended material to move into macropores deeper within the column. Micropores in the column absorb the water and thin silt or clay films develop which then coat the macropore walls. The particles remain as a coating that becomes thicker with every cycle of drying and wetting (Fernández et al. 2002).

Silt coatings develop under a number of conditions including: "high-energy conditions when the soil surface was temporarily submerged during flooding (McCarthy and Plint 1998:389), in colder temperatures because of freeze-thaw activities, or lithological discontinuities (Fedoroff et al. 1990; McCarthy and Plint 1999). Silt coatings developed during vertical frost sorting, are a result of freeze and thaw of pore water that causes sediment movement, and fluvatile sedimentation (i.e. gravitational flow) (Mücher and Morozova 1981:163; Van Vliet Lanoë 1998).

The void, grain coatings and hypo-coatings suggest water percolated through sections of the profile where there was periodic wetting and drying of sediments. This process can also cause shrinking and swelling of sediments, the intermixing and rounding of free grain argillans and other minerals during transport and the collection and

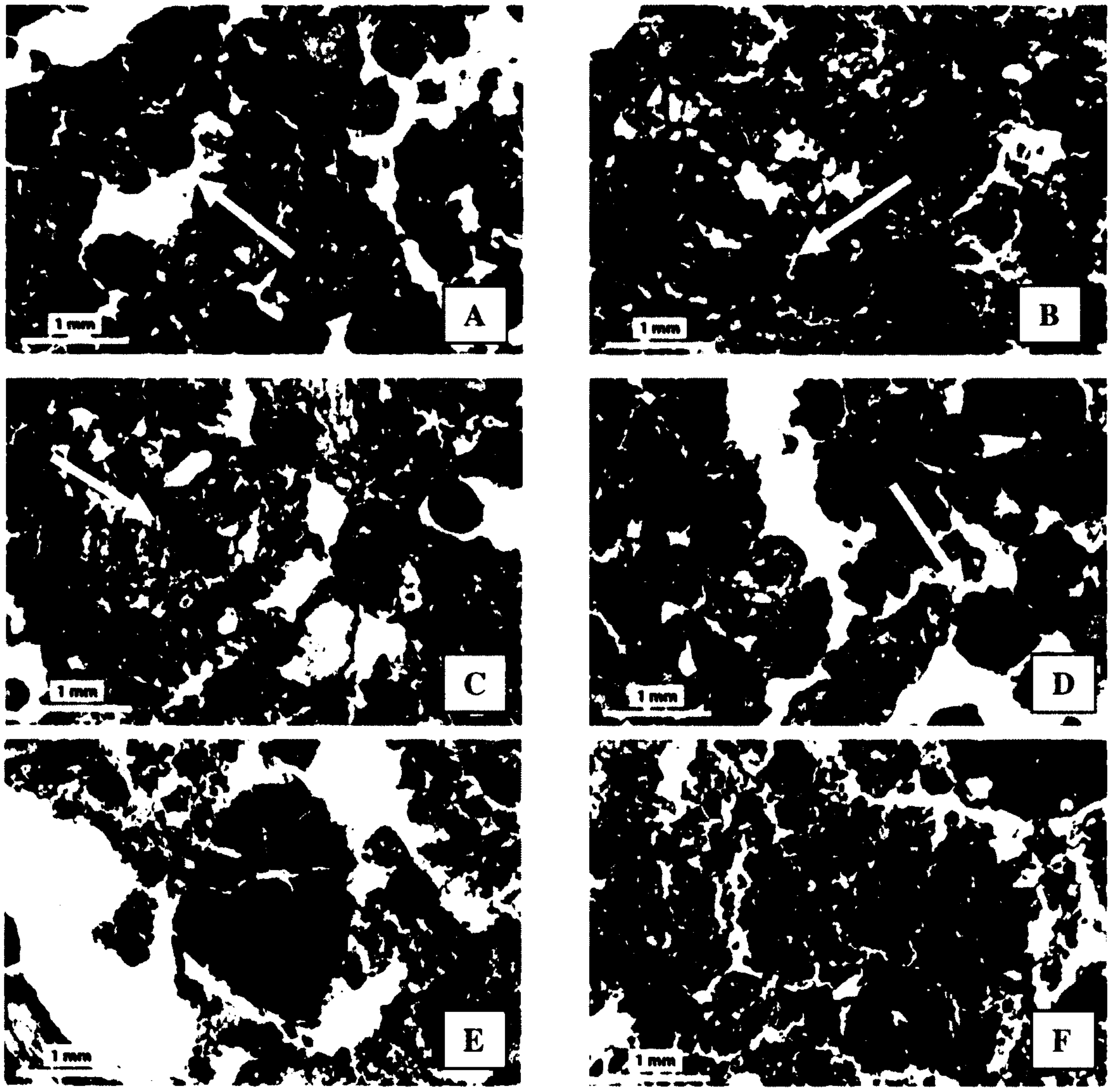


Figure 4.11 (A) Thin section photo illustrating a rounded clay papule (arrow); (B) Diffuse clay nodule that developed in situ (arrow); (C) Rounded nodule (arrow); (D) Rounded nodule (arrow); (E) Nodule with silt coating and internal cracking indicating manganese reduction; (F) Example of ferrihydrate staining on sediments.

development of preferred orientation of sediment clasts (Bockheim 1979:289; Bullock and Murphy 1979:233, McCarthy and Plint 1999:303).

The prevalence of coatings throughout the profile may also result from potassium and magnesium enrichment. A number of microfacies containing coatings are associated with decayed organics derived from the human occupations. The coatings are caused by the breakdown of organics that enrich sediments with potassium and magnesium and promote the translocation of clay and possibly silt particles (Courty et al. 1989:129).

As Mink Island is located in the coastal sub-arctic zone of Alaska, the accumulation of coatings in sections of the profile suggests that both translocation (of water and silt), and freeze-thaw processes created the silt coatings observed throughout the profile. Simpson and Barrett (1996:554) suggest, based on their study of a coastal midden in Scotland, that thin clay coatings lacking laminations, are associated with short-term, possibly seasonal, formation and the movement of fine material from un-vegetated surfaces prior to burial. Silty-clay textural pedofeatures observed infrequently indicate longer periods of pedogenesis and a lack of deposition (Simpson and Barrett 1996:554).

The diffuse borders displayed by many of the coatings at Mink Island indicate *in situ* development during periods of sediment stability (i.e., no erosion, or deposition) in sections of the deposit. However, rounded silt coatings on grains in other locations suggest secondary deposition of these particles, or extensive bioturbation or cryoturbation. The uneven distribution of the coatings and their rounded surficial exteriors may indicate that the grain coatings developed in a stable deposit, which later experienced disturbance and movement that wore down and rounded the coating surfaces (Bullock and Murphy 1979:245; Kemp et al. 1992; Mücher and Morozova 1981:165). The coatings remained attached to the grains suggesting movement probably occurred during freezing temperatures; motion in warm temperatures causes coating removal (Kemp 1985). Drivers of the grain redeposition include erosion, likely caused by aeolian or colluvial (downhill) movement of sediments (Bullock and Murphy 1979:245; Mücher and Morozova 1981:165).

Rounding of coatings by bioturbation (McCarthy and Plint 1998:389) and possibly cryoturbation is also possible. However, rounded clay papules are also observed in sections of the profile; these are indicative of deposition via low-energy erosion during freezing temperatures (Brewer 1964:282; McCarthy and Plint 1999:303; Mücher and Morozova 1981:165). Papules, much like fecal pellets, are indicative of soil formation, but when the borders are rounded as here, they have more than likely undergone secondary deposition (Brewer 1964; Durn 2006:95; McCarthy and Plint 1998:389; Mücher and Morozova 1981:154). In general, the thin silt coatings suggest short-term cycles of deposition and non-deposition, although the microscopic evidence might also represent a shift in the use of a specific area within the site and therefore, a change in depositional patterns (Simpson and Barrett 1996:554). The difference between the two is not recognizable, and both processes are possible.

Because the silt coatings are thin and not laminated it suggests some sections of the deposit were somewhat unstable; thick coatings require stable deposits that allow movement of water through the profile in consistent locations (McCarthy 2002; McCarthy personal communication 2010). Other sections of the deposit appear more stable allowing for the development of diffuse void and grain coatings, and diffuse clay pedofeatures.

The features observed indicate a number of processes acted on the site. Inputs of water allowed for the translocation of silt particles and the creation of coatings. The coatings further developed during subsequent freeze-thaw processes associated with seasonal temperature changes. Coating development was interrupted during periods of sediment surface instability. The rounded uneven grain coatings and rounded papules indicate low-energy erosion and some *in situ* bioturbation.

4.9.7 Ferruginous Features-Nodules and Ferruginous Stains

The profile contains a considerable number of ferruginous nodules of varying types. The most common are typic amorphous and polymorphic nodules. Typic amorphous nodules have sharp boundaries and undifferentiated internal fabrics (Bullock et al. 1985:104) [Figure 4.11©, Level 28-II 118-127 cmbs, Slide 12; Figure 4.11 (D), Level 29-II, 118-126 cmbs, Slide 13]. There are a few instances of nodules with internal cracking [Figure 4.11(E), Level 27-4 and BBF1 102-108 cmbs, Slide 10] which may indicate a reduction in the amount of manganese present. Nodules with sharp borders may also indicate vertical displacement (Brewer 1964:282; McCarthy and Plint 1999:303; Mücher and Morozva 1981:165). A section in the lower portion of the profile contains ferruginous nodules with diffuse borders in association with void silt coatings, both of which suggest deposit stability.

Ferrihydrite is the probable cause of the brown and reddish-brown color of the ground mass observed through most of the deposit (Lindbo et al. 2009; Miedema et al. 1974) (Figure 4.11 F, Level BBF-1, 102 to 108 cmbs, Slide 10). In several sections light brown/yellow sediments are present, with the yellow possibly the mineral goethite (Birkeland 1984:100), which could have developed during oxidizing conditions in conjunction with the slow release of iron from organic material present in the sediments (Birkeland 1984:100).

4.9.8 Interpretation of Ferruginous Features

Manganese and iron nodules with sharp borders in groundmass indicate short distance transport of ferrous material through the profile while nodules with diffuse boundaries suggest local aeration and *in situ* formation; sharp nodule borders may be indicative of movement or bioturbation (causing a rounded nodule border) (Bouma et al. 1990:267; McCarthy et al. 1998). The nodules and ferrihydrite staining are associated with the release of ferric-oxides from organic material (Miedema et al. 1974:317) deposited during human occupation of the site, followed by eluviation of the material and its subsequent impregnation into the ground mass in a more oxidizing environment (Lindbo et al. 2009). Release of soluble iron from organics also caused the opaque coloring of sediment underlying some of the living floors. In microsites containing enough organic material, dissolved oxygen will be consumed rapidly by decomposing microorganism, which causes the reduction first of manganese (producing the black color) then iron (Lindbo et al. 2009). The presence of water that enabled solution and translocation of minerals was likely available for only short periods of time thus producing manganese nodules are in a relatively short time scale (Lindbo et al. 2009).

The short-term availability of water or ponding events may also be suggested by the lack of depletion features; these generally do not develop over short-term events (Vepraska et al. 2006). Similarly, the presence of red staining in only some sections of the profile indicates limited movement of water and only some places with suitable conditions for redoximorphic processes. These require sufficient stagnant or un-oxygenated water, sufficient organic material and microorganisms, and temperatures above biological zero (5°C) (Lindbo et al. 2009; Vepraskas et al. 2006:487). The limited presence of these features suggests that one, if not more, of the required water and oxygen conditions were not met throughout the entire profile at all times. In addition different pore sizes in different locations can result in faster and/or slower diffusion of iron into the matrix (McCarthy 2011, personal communication). The onset of colder winter months with reduced temperatures may have stopped the redoximorphic processes (Lindbo et al. 2009; Vepraskas et al. 2006:487). Simpson and Barrett (1996:549) found similar ferruginous staining in midden deposits in coastal Scotland, and suggested these features may also represent surface pedogenesis of sediments. These differences likely worked in conjunction with the water inputs and oxygen conditions, as well as the temperature fluctuations.

While the rounded nodules could reflect secondary deposition (i.e., brought in from another location), given the extensive amount of organic material with which they are associated, it is thought that the rounded boarders are more likely a result of pedogenic processes, and possibly cryoturbation (Miedema et al. 1974).

4.9.9 Anthropogenic Features

Occupation levels clearly display larger grain sizes and an abundance of large pieces of organic material, such as bone and plant fragments (see Figure 4.10). The anthropogenic organics show evidence for natural decomposition not displaying gray, fine-grained minerals with high interference colors indicative of ash and burning (Courty et al. 1989; Simpson et al. 1998:1189). Chitonic and close porphyric distributions of groundmass were most commonly associated with occupation floors, as was material compaction; the latter is likely the result of human trampling or post-depositional processes such as bioturbation (Angelucci 2006:10).

4.10 Discussion

The sediments in the Mink Island archaeological site profile illustrate pedogenic processes during periods of deposit stability. However, the number of different processes are difficult to discern because of the impact of the various human occupations. Together, pedogenic processes and human actions created a complex profile from which information on site formation is difficult to extrapolate. Nevertheless, some specific processes influencing deposit development were identified.

The Mink Island profile displays evidence for the rapid deposition of material from human occupation that inhibited pedogenesis, and initially creating surface sediment instability; occupation also affected the content and structure of the sediments, ultimately leading to sediment compaction that effectively sealed off underlying non-cultural sediments and limiting or halting the pedogenic processes in some sections of the profile.

During the various periods of human abandonment, surface stabilization occurred and drainage increased allowing silt and soluble mineral translocation through portions of the deposit. This was regularly interrupted by seasonal freeze-thaw processes. The addition of highly organic anthropogenic material increased the availability of Fe-oxides and translocation of these particles generated the many nodules and the ferryhydrite staining observed within the profile [refer to Figure 4.10 (A) above].

In general, the sediments do not display a polygentic origin which would provide a better indicator of a change in the local climate. The same features are present throughout the profile, indicating repetitive pedogenic processes including the regular wetting and drying of sediments, the release of ferruginous material from the human deposited organic matter, and the freezing and thawing of sediments. The features present indicate the profile developed along a relatively simple pathway. Figure 4.12 illustrates development in response to environmental factors such as translocation, although the human occupation was ultimately the driving factor in midden growth.

Deposit stability and pedogenic processes are evident throughout in the form of illuvated silt particles forming void and grain coatings. Spongy microstructures dominate the culturally sterile levels indicating periodic depositional hiatuses and suggesting little post-depositional disturbance (Simpson et al. 1998:1188). The absence of root traces and channels may result from repetitive human occupation preventing extensive vegetation growth and root development; this may have been compounded by bioturbation and over-burden pressure that caused root channel collapse, and weak soil development (Bertran and Texier 1999:102).

Throughout depositional processes are documented as colluvial and aeolian in nature. The dominant natural depositional process is low-energy erosion. This erosion was either colluvial (gravity-transport), or aeolian (wind-blown), over a short distance. Both processes probably acted in conjunction; wind is plentiful and only a small incline is

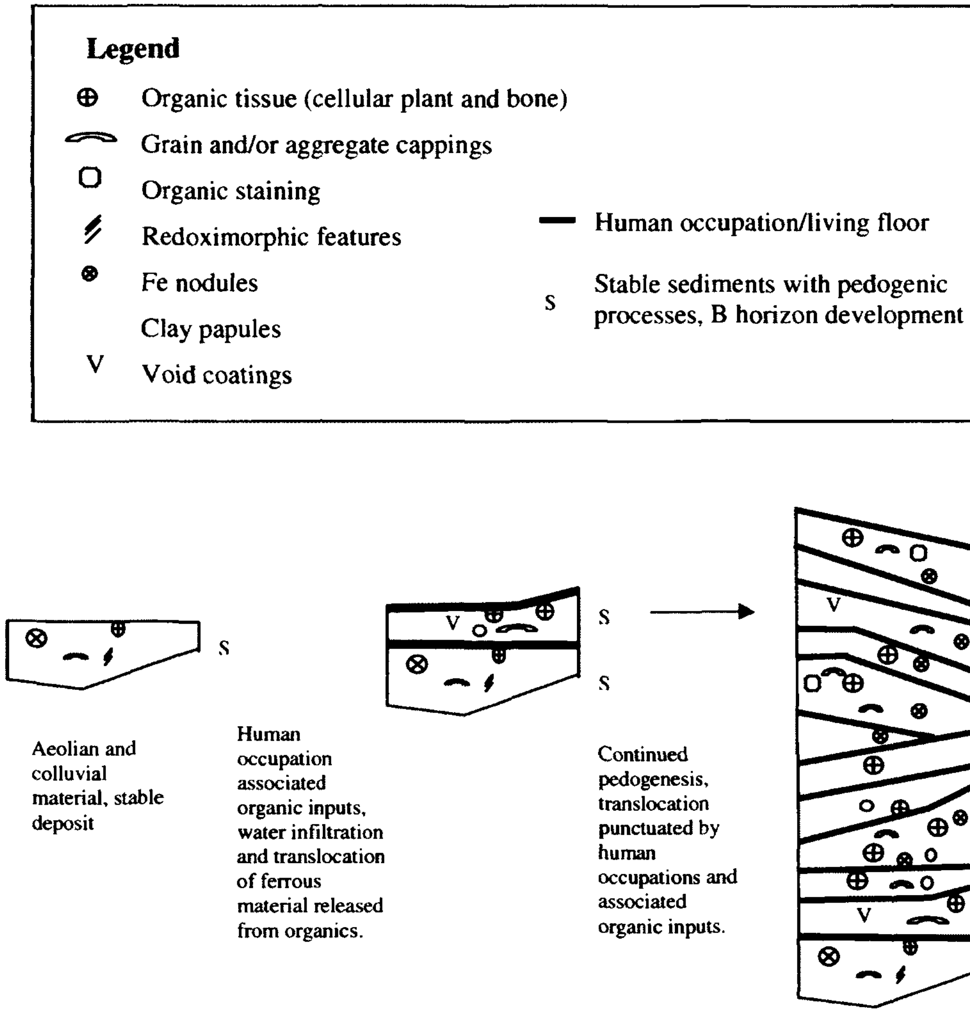
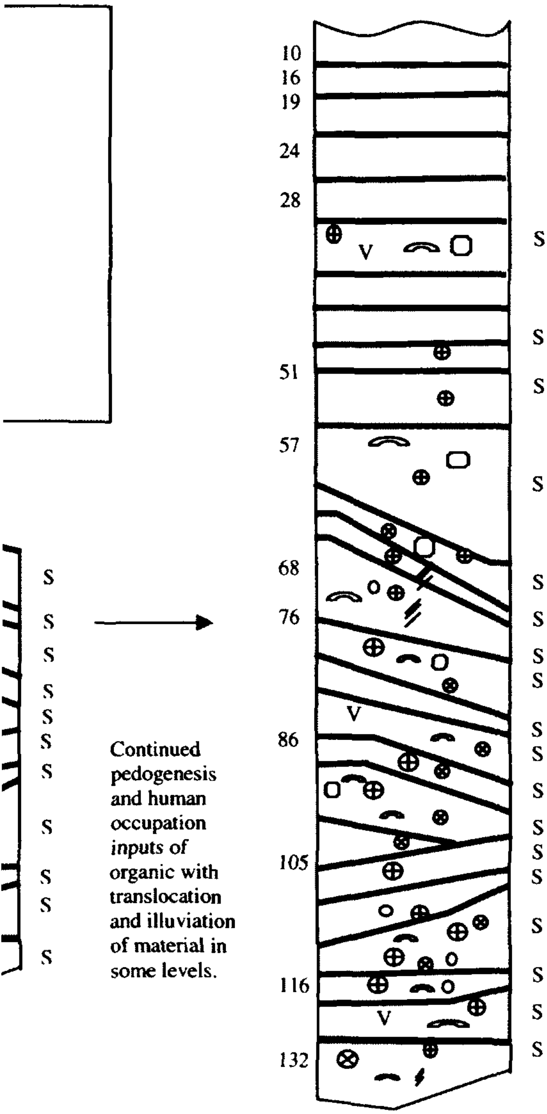


Figure 4.12 Schematic illustration of the lower midden development.


10
16
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57
68
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86
105
116
132
S
V
Continued pedogenesis and human occupation inputs of organic with translocation and illuviation of material in some levels.

required for downslope movement and both can result in the external wear observed on silt grain coatings (Courty et al. 1989). However, the lack of sorting generally associated with wind action (see also Hilton 2002:281) suggests colluvial processes dominated (Emerman et al. 2002; Visher 1969).

The intact rounded silt grain coatings and rounded clay papules suggest that secondary deposition occurred during freezing temperatures. Because these features occur between occupation floors it is suggestive of winter abandonment of the site. This is a useful line of evidence for season of occupation, especially when combined with analysis of faunal material from occupation levels. For example, Strathe's (2008) analysis of phocidae fauna from the Upper Midden also suggests some winter season abandonment with direct evidence for winter sealing in only five of 22 occupation levels that contained seal remains.

The Mink Island sediments also show evidence of reducing conditions and episodic wetting and drying events as expected in periglacial and temperate environments For instance, several microfacies in the profile have characteristics suggestive of redoximorphic processes, where oxygen reduction and oxidation has occurred. Almost all of these are associated with human occupations, which would have provided the organic material from which the ferrous material was removed. The limited distribution of redoximorphic features suggests solution and translocation of minerals was periodic, and that conditions were not conducive to extensive redoximorphic processes throughout the deposit. Evidence for these processes is generally associated with living floors, (with the exception of the two red ochre floors), and it is possible that the compact organic rich floors allowed for pooling and freezing of water during the winter months. With the onset of warmer months the water melted creating limited saturation in some cases, and with warmer temperatures and increased microorganism activity some redoximorphic processes were enabled. As iron depletion zones or gleyed areas were not observed either macroscopically and microscopically, the sediments were probably never saturated for an extensive period or water stagnation was probably minimal. The possible link between the formation of redoximorphic features and increased water inputs during winter months, when there is more precipitation and there are more storms (Spooner et al. 2003; Wilson and Overland 1989) is explored further in Chapter 5.

Chapter 5

Grain-size and Scanning Electron Microscopic Analysis of Sediments

5.1 Introduction

Changes in depositional or erosional regimes along the coast are often indicative of water energy fluctuations. High-energy coastal environments are associated with the deposition of larger sized sediment grains while low energy environments are generally associated with the deposition of smaller, finer-grained sediment particles. Site placement relative to the active shoreline is suggested by sediment grain sizes, with larger particles, cobbles and pebbles generally indicative of swash zone or mid-beach settings and smaller-grained particles associated with offshore/littoral environments. As such, grain-size analyses were conducted in an effort to identify possible changes in depositional or erosional regimes that may suggest changes in relative sea level or local climate conditions.

Grain-size analysis enables determination of the distribution of grains according to their size class in a given sample. Statistical analysis of data enables comparison with grain-size data from other locations with sediments of known origins and the depositional environment for those of unknown origin may be inferred (Gilbertson et al. 1992). Particle-size analysis is crucial as "all other analytical data cannot be validly interpreted without reference to the particle size composition…" (Baize 1993:34). Textural properties allow characterization and description of the site deposits and assist in identifying the depositional environment, and in paleogeographic reconstruction (Fieller et al. 1992; Gilbertson et al. 1992).

5.2 Methods

Grain-size analysis was conducted on almost all of the sediment material excavated during the 2000 field season. However, most of the fine-grained material was lost as sediments were wet sieved with mesh apertures of 3 mm or -1.6 Φ in the field before they were made available for analysis. In the field lab, the material that remained after wet sieving was passed through a set of geological sieves sized 12500 microns (12.5 mm, -3.6 Φ), 9500 microns (9.5 mm, -3.2 Φ), 5600 microns (5.6 mm, -2.4 Φ), 1580 microns (1.58 mm, -0.7 Φ) and 500 microns (0.5 mm, 1 Φ). The weights of materials in each of the size groups were recorded and the results were statistically analyzed upon return from the field.

Unscreened bulk sediment samples were also collected. Several of these unscreened, bulk samples were selected for grain size analysis to obtain a sample of the fine-grained material lost from the wet-sieved samples. These unscreened samples were pretreated (see below) and processed prior to dry screening in the lab.

As documenting changes in local environmental conditions was of greatest interest, sediment samples were selected based field notes indicating they were from non-cultural levels. Sediments from between living floors are less likely to have been influenced by human presence which can alter composition and confound attempts to infer environmental conditions and depositional/erosional processes. Forty-three bulk sediment samples that met one or more of the following criteria were selected: 1) sample location in the profile above or below an occupation level; 2) samples from obvious natural deposits such a tephra; and 3) samples from levels noted in the field as water or aeolian deposits. Table 5.1 presents the list of bulk samples used in the analysis.

Table 5.1 Post-field Work Bulk Samples Used in Grain-size Analysis.

Sample	Level	Sample	Level	Sample	Level
So 53	Dune	So 198	21	So 51	35
So 63	Dune	So 184	23	So 76	35
So 54	Dune	So 203	24	So 117	38
So 107	PBF10	So 215	25	So 112	38
So7	12	So 249	26	So 119	38
So 21	13	So 1	27	So 136	40
So 10	13	So 6	27	So 159	KE
So 41	15	So 12	27-2	So 115	39
So 37	15	So 5	27-3	So122	39
So 84	15	So 7	27-4	So 113	46
So 63	16	So 34	30	So 185 (2000)	49
So 85	18	So 46	32	So 157	49
So 73	17	So 42	33	So 156	50
So 94	20	So 68	34	So 189	51
				So 236	OF2

To generate a better understanding of changes through time, all samples were grouped based on their unit of origin and vertical depth in the site deposit to account for potential depositional differences across units.

5.2.1 Bulk Sample Pre-treatment Procedures

Bulk samples were subdivided into 250 gram (g) and 10 g subsamples. The 250 g samples were used for particle-size analysis and the smaller 10 g samples were set aside for scanning electron microscope analysis. Only organic material was removed from the 250g samples, as carbonates do not affect the results of particle size analysis to any measurable degree (Baize 1993). Samples used in particle-size analysis are commonly pre-treated to remove organics, and soluble minerals as they act as coagulants (Baize 1993; Day 1965:573) causing the grains to bond together and inhibit movement through the sieves. In addition to organics, carbonates were also removed from the samples used in the scanning electron microscope analysis; adhesion of carbonates makes it difficult to clearly view the grain surfaces. Methods used to remove organics, carbonates and any other soluble materials followed Day (1965), Gee and Bauder (1986), Kunze (1965), and Kunze and Dixon (1986).

The samples were heated in an industrial oven for between seven and eight hours at temperatures between 350°F and 450°F. Temperatures in this range are high enough to burn off organics, but not high enough to alter the mineral structure (Jackson 1958:223), thus the mineralogical attributes of the sediments are preserved for X-ray analysis with a scanning electron microscope, or microprobe.

After heating, the samples were reweighed to assess mass lost through heating, and to obtain sample weight prior to sieving (Table 5.2). Some sediments are lost during sieving as a fraction are dispersed into the air (for small clay-sized particles). Particles may also be retained within sieves and some spilt while transferring sediments.

5.3 Grain-size Sorting Procedures for Bulk Samples

A set of geological sieves was used to process the bulk sediment samples following removal of the organics. The sieves are numerically identified as 5, 10, 18, 35, 60, 120, and 230. The corresponding mesh opening size for each sieve, from 5 to 230 consecutively is 4 mm, 2 mm, 1 mm, 500 microns, 250 microns, 125 microns, and 63 microns.

Table 5.2 Post-field Work Bulk Sample Weights Before and After Heating.

Sample Numbers	**Level**	**Pre-heat Weight**	**Post-heat Weight**	**Sample Numbers**	**Level**	**Pre-heat Weight**	**Post-heat Weight**
53	Dune	250	242	12	27-2	250	248
63	Dune	250	240	5	27-3	250	238
54	Dune	250	252*	7	27-4	250	248
107	PBF10	250	232	34	30	250	238
10	12	250	238	46	32	250	222
7	12	250	232	42	33	250	238
21	13	250	234	68	34	250	245
41	15	250	226	51	35	250	276*
37	15	250	228	76	35	250	252*
84	15	250	278*	117	38	250	236
63	16	250	168*	119	38	250	242
73	17	250	240	112	38	250	246
85	18	250	230	159	KE	250	159
72	18	250	250	122	39	250	242
94	20	250	242	115	39	250	242
198	21	250	244	131	40	250	260*
184	23	250	260*	136	40	250	242
203	24	250	248	113	46	250	244
215	25	250	238	157	49	250	222
249	26	250	226	184 (2000)	49	250	110
1	27	250	232	189	51	250	242
6	27	250	238	236	OF2	250	250

***After weights being greater than the original 250 g are believed to be a result of error during pre-heat weighing.**

The weight of each sieve was recorded and they were arranged from largest mesh opening (sieve No. 5) to the smallest mesh opening (sieve No. 230), atop a pan that collects any material smaller than 0.0625 mm. After the sieve column was assembled, it was placed in an electrical shaker and a sample poured into the top. Each sample was agitated for ten minutes, the standard time to allow particles to sort through the column (Baize 1993). After shaking, each sieve and its contents were weighed. The weight of the sieve was subtracted to obtain the size class weight that was recorded on prepared sheets. The silt and clay particles remaining in the pan at the base of the column were also weighed, although not subject to further analysis.

5.4 Gradistat Statistical Analysis

The weight of all samples, whether bulk or field wet-screened, was entered into an Excel spreadsheet and imported into the Gradistat program. Gradistat is a statistical program developed by Simon Blott (2000) at the Department of Geology at Royal Holloway University of London. The program was created using Microsoft Visual Basic and calculates Method of Moments statistics for the user. These include: mean, mode, sorting (standard deviation), skewness, kurtosis, D_{10}, D_{50}, D_{90}/D_{10}, D_{90}-D_{10}, D_{75}/D_{25}, and D_{75}-D_{25} (interquartiles). The program calculates grain size parameters arithmetically, geometrically in microns and logarithmically using the phi scale (Blott 2000). The statistical parameters advocated by Folk and Ward (1957), are used to generate a graph that illustrates sediment physical sizes. Each sample is also described texturally after Folk (1954) (Blott 2000), and tables are generated showing the percentage of grains that fall into different size fractions based on the Udden (1914), and Wentworth (1922) scales (Blott 2000).

5.5 Method of Moments Equations Used in Gradistat and their Meaning

The following equations are used for method of moments calculations in the Gradistat program where f is the frequency percent; m is the mid-point of each class interval in metric (m_m) or phi (m_Φ) units; P_x and Φ_x are grain size diameters in metric and in phi units, at the cumulative percentile value of x (Blott 2000).

5.5.1 Logarithmic Method of Moments Equations

Mean $x_{\Phi} = \dfrac{\sum fm_{\Phi}}{100}$

Standard Deviation $\sigma_{\Phi} = \dfrac{\sqrt{\sum f(m_{\Phi} - x_{\Phi})^2}}{100}$

Skewness $Sk_{\Phi} = \dfrac{\sum f(m_{\Phi} - x_{\Phi})^3}{100\sigma_{\Phi}{}^3}$

Kurtosis $K_{\Phi} = \dfrac{\sum f(m_{\Phi} - x_{\Phi})^4}{100\sigma_{\Phi}{}^4}$

5.5.2 Logarithmic (Original) Folk and Ward (1957) Graphic Measures

Mean $M_z = \dfrac{\Phi_{16} + \Phi_{50} + \Phi_{84}}{3}$

Standard Deviation $\sigma_1 = \dfrac{\Phi_{84} - \Phi_{16}}{4} + \dfrac{\Phi_{95} - \Phi_5}{6.6}$

Skewness $Sk_1 = \dfrac{\Phi_{16} + \Phi_{84} - 2\Phi_{50}}{2(\Phi_{84} - \Phi_{16})} + \dfrac{\Phi_5 + \Phi_{95} - 2\Phi_{50}}{2(\Phi_{95} - \Phi_5)}$

Kurtosis $K_G = \dfrac{\Phi_{95} - \Phi_5}{2.44(\Phi_{75} - \Phi_{25})}$

The most common statistical procedure, the Folk and Ward (1957) method (Blott and Pye 2001; Gilbertson et al. 1992) estimates low order sample moments such as mode, mean, median, sorting, kurtosis and skewness (Gilbertson et al. 2004). These measures are obtained by graphical estimation from log-normal probability plots, with the assumption that the sediments have a log normal distribution (Fieller et al. 1992; Gilberston et al. 2004).

A log normal distribution is a distribution that is skewed (where a distribution is negatively or positively clustered) and that can be transformed into a *normal*, bell-shaped distribution by converting the values to logarithms (Wellmer 1998: 358). Although different methods can be used, whereby both the size and frequency scales are logarithmically transformed as in the case of the log-hyperbolic distribution (Bagnold and Barndorff-Nielsen 1980; Hartmann and Christiansen 1992; Knight et al. 2002; Sutherland and Lee 1994), the ability of this transformation to generate greater insight into grain size distributions has yet to be shown (Blott and Pye 2001:1238).

To obtain the logarithmic values, the geometric average is multiplied by a log factor, either a natural log which is defined as e=2.7183, or a decimal logarithm to the base of 10 (Wellmer 1998:67). Logarithmic values are also used to establish the mean, the variance, and the standard deviation (Wellmer 1998:67).

The geometric average is the mean and it is calculated by multiplying a series of values in a data set and then taking the *n*th root of this product, where *n* is the number of values in the data set; the formula for this calculation is $gm={}^{n}\sqrt{x_1x_2x_3 \ldots x_n}$. The arithmetic mean is also referred to as the average. It is obtained by summing the values of a data set and dividing this by the number of values in the data set (x+x+x)/N.

In essence, one transforms the values from one type of number to another, such as when Fahrenheit is transformed to Celsius. If these data are then plotted graphically, the values for both sets lie on a straight line. This method of changing one value unit to another is referred to as a linear transformation (Dallal 2001). In linear transformations the space between the values remains the same before and after transformation. Conversely, non-linear transformations do not preserve this equal spacing between values (Dallal 2001). Logarithmic transformations are nonlinear. In a common log scale if a value is multiplied by ten in the original scale, one unit is added to its value in the log scale. If a unit is divided by ten in the original scale one unit is subtracted from one in the log scale (Dallal 2011). Therefore, on the original scale the units move from 0.1 to 1 to 10, on a logarithmic scale they move from -1 to 0 to 1 (Dallal 2011).

The main reason for the use of logarithms is their ability to facilitate different statistical techniques by generating single-peaked data. They also enable comparisons of different data sets by reducing the variability among them, and they facilitate the description of variables and the relationships among them when approximate linearity can be achieved (Blott and Pye 2001; Dallal 2001). Importantly, for grain size analysis, logarithmic transformation reduces the amount of positive skew (Dallal 2001; Wellmer 1998).

Normal distributions are rare in nature, and it is the skew and kurtosis of a sample that are the important indicators of the size distribution of the sediments. Skewed distributions have values that cluster towards one end of the distribution curve and tail off to the other. A positively skewed distribution is where the tail of the distribution curve extends to the right, and a negative distribution is where the tail of the distribution curve extends to the left (Lowry 2004). Whether the skew of a distribution is positive or negative is important as positively skewed distributions indicate an excess of fine-grained material and negatively skewed distributions indicate an excess of coarser particles (Blott and Pye 2001:1242).

The other value of importance, kurtosis, indicates the shape of the distribution curve, whether it is mesokurtic or medium curved (where there are no extreme groupings of values along the curve), platykurtic (when the curve is short and flat), or leptokurtic (where the curve is tall and slender). Mesokurtic distributions are more moderate then leptokurtic ones, and leptokurtic distributions have curves that fall from peaks and are more tapered in shape than platykurtic distributions (Lowry 2004). Tables 5.3 to 5.6 illustrate the numerical indicators of kurtosis for each method of moment calculation.

Table 5.3 Derived Numerical Value Indicators Arithmetic and Geometric Method of Moments.

Sorting (σ_g)	**Skewness (Sk_g)**	**Kurtosis (K_g)**
Very well sorted, <1.27	Very fine skewed, $<^{-}1.30$	Very platykurtic, <1.70
Well sorted, 1.27-1.41	Fine skewed, $^{-}1.30$-$^{-}0.43$	Platykurtic, 1.70-2.55
Moderately well sorted, 1.41-1.62	Symmetrical, $^{-}0.43$-$^{+}0.43$	Mesokurtic, 2.55-3.70
Moderately sorted, 1.62-2.00	Coarse skewed, $^{+}0.43$-$^{+}1.30$	Leptokurtic, 3.70-7.40
Poorly sorted, 2.00-4.00	Very coarse skewed, $>^{+}1.30$	Very leptokurtic, >7.40
Very poorly sorted, 4.00-16.00		
Extremely poorly sorted, >16.00		

Table 5.4 Derived Numeric Value Indicators for Logarithmic Method of Moments.

Sorting (σ_ϕ)	**Skewness (Sk_ϕ)**	**Kurtosis (K_ϕ)**
Very well sorted, <0.35	Very fine skewed, $>^{+}1.30$	Very platykurtic, <1.70
Well sorted, 0.35-0.50	Fine skewed, $^{+}0.43$-$^{+}1.30$	Platykurtic, 1.70-2.55
Moderately well sorted, 0.50-0.70	Symmetrical, $^{-}0.43$-$^{+}0.43$	Mesokurtic, 2.55-3.70
Moderately sorted, 0.70-1.00	Coarse skewed, $^{-}0.43$-$^{-}1.30$	Leptokurtic, 3.70-7.40
Poorly sorted, 1.00-2.00	Very coarse skewed, $<^{-}1.30$	Very leptokurtic, >7.40
Very poorly sorted, 2.00-4.00		
Extremely poorly sorted, >4.00		

Table 5.5 Derived Numeric Value Indicators for Logarithmic Folk and Ward Graphic Measures.

Sorting (σ_I)	**Skewness (Sk_I)**	**Kurtosis (K_G)**
Very well sorted, <0.35	Very fine skewed, $^{+}0.3$-$^{+}1.0$	Very platykurtic, <0.67
Well sorted, 0.35-0.50	Fine skewed, $^{+}0.1$-$^{+}0.3$	Platykurtic, 0.67-0.90
Moderately well sorted, 0.50-0.70	Symmetrical, $^{+}0.1$-$^{-}0.1$	Mesokurtic, 0.90-1.11
Moderately sorted, 0.70-1.00	Coarse skewed, $^{-}0.1$-$^{-}0.3$	Leptokurtic, 1.11-1.50
Poorly sorted, 1.00-2.00	Very coarse skewed, $^{-}0.3$-$^{-}1.0$	Very leptokurtic, 1.50-3.00
Very poorly sorted, 2.00-4.00		Extremely leptokurtic, >3.00
Extremely poorly sorted, >4.00		

Four parameters are used to determine grain size distribution: 1) the average size; 2) the spread (sorting) of the sizes around the average; 3) the symmetry or preferential spread (skewness) to one side of the average; and 4) the degree of concentration of the

Table 5.6 Derived Numeric Value Indicators for Geometric Folk and Ward Graphic Measures.

Sorting (σ_G)	**Skewness (Sk_G)**	**Kurtosis (K_G)**
Very well sorted, <1.27	Very fine skewed, $^{-}0.3$-$^{-}1.0$	Very platykurtic, <0.67
Well sorted, 1.27-1.41	Fine skewed, $^{-}0.1$-$^{-}0.3$	Platykurtic, 0.67-0.90
Moderately well sorted, 1.41-1.62	Symmetrical, $^{-}0.1$-$^{+}0.1$	Mesokurtic, 0.90-1.11
Moderately sorted, 1.62-2.00	Coarse skewed, $^{+}0.1$-$^{+}0.3$	Leptokurtic, 1.11-1.50
Poorly sorted, 2.00-4.00	Very coarse skewed, $^{+}0.3$-$^{+}1.0$	Very leptokurtic, 1.50-3.00
Very poorly sorted, 4.00-16.00		Extremely leptokurtic, >3.00
Extremely poorly sorted, >16.00		

grains relative to the average (kurtosis) (Blott and Pye 2001: 1238-1239). These measures are obtained using methods of moments, with the formulae of methods advocated by Friedman (1961) and graphical measures described by Folk and Ward (1957). These are the most widely used methods of moment measures; they are regarded as 'better' because they use all numbers in the distribution, rather than only a few percentiles like those advocated by Folk and Ward (1957), (Blott and Pye 2001:1240; Folk 1966; Gilbertson et al. 1992; Sutherland and Lee 1994:1133).

5.6 Grain-size Analysis Findings

The weights of each sieve and its sediment contents were entered into the Gradistat program and mean, median, mode, skew and kurtosis for each level was computed in both method of moments and in the Folk and Ward graphical procedure. Bulk samples and field wet-screened samples were initially examined as two separate groups. Subsequently, they were grouped by excavation unit (i.e., unit 1LS1LE) and the grain sizes plotted. The tables indicating the particle size distribution for bulk and water screen samples derived from these units are found in Appendix IV. There are water-screened samples from all units but 2LS1LW, 2LSOLE, OLN1LE, and OLN2LE thus these four units are not represented in Figure 5.2 (Figures 5.1-5.2). Bulk samples are from units 1LS1LE, ILS2LE, 1LS0LE, 1LS1LW (Figures 5.3-5.4). These units contained more four or more sediment samples providing a large enough sample size to examine differences between the levels.

5.7 Summary

The average grain size of sediments from the bulk samples is relatively consistent between units with the average grain size clustering at 2 Φ (between moderate and fine sand). The bulk samples also indicate only a small proportion of fine sand, silt or clay sized particles. Beach sediments generally do not contain silt and clay grains as these remain in suspension and are deposited further from the shoreline, leaving only coarse material along the beach (Pontee et al. 2004; Pyökäri 1999; Wells 2001). However it is difficult to generalize about each of the levels here because each sample is from a different unit, representing only that specific location at the time of deposition and not necessarily the whole level within the site. It is clear that there were localized differences but it is difficult to synthesize depositional changes throughout the deposit.

If a marine transgression occurred at the site, there should be a level that containing silt and clay sized grains as they would have been within the foreshore instead of the backshore zone. The grain size distributions suggest that the site was generally in the backshore zone, beyond the breaking waves. Storm surges, which generally remove the fine material from sediment deposits (Reineck and Singh 1980), may have occurred at different points in time but they have not left any definitive evidence.

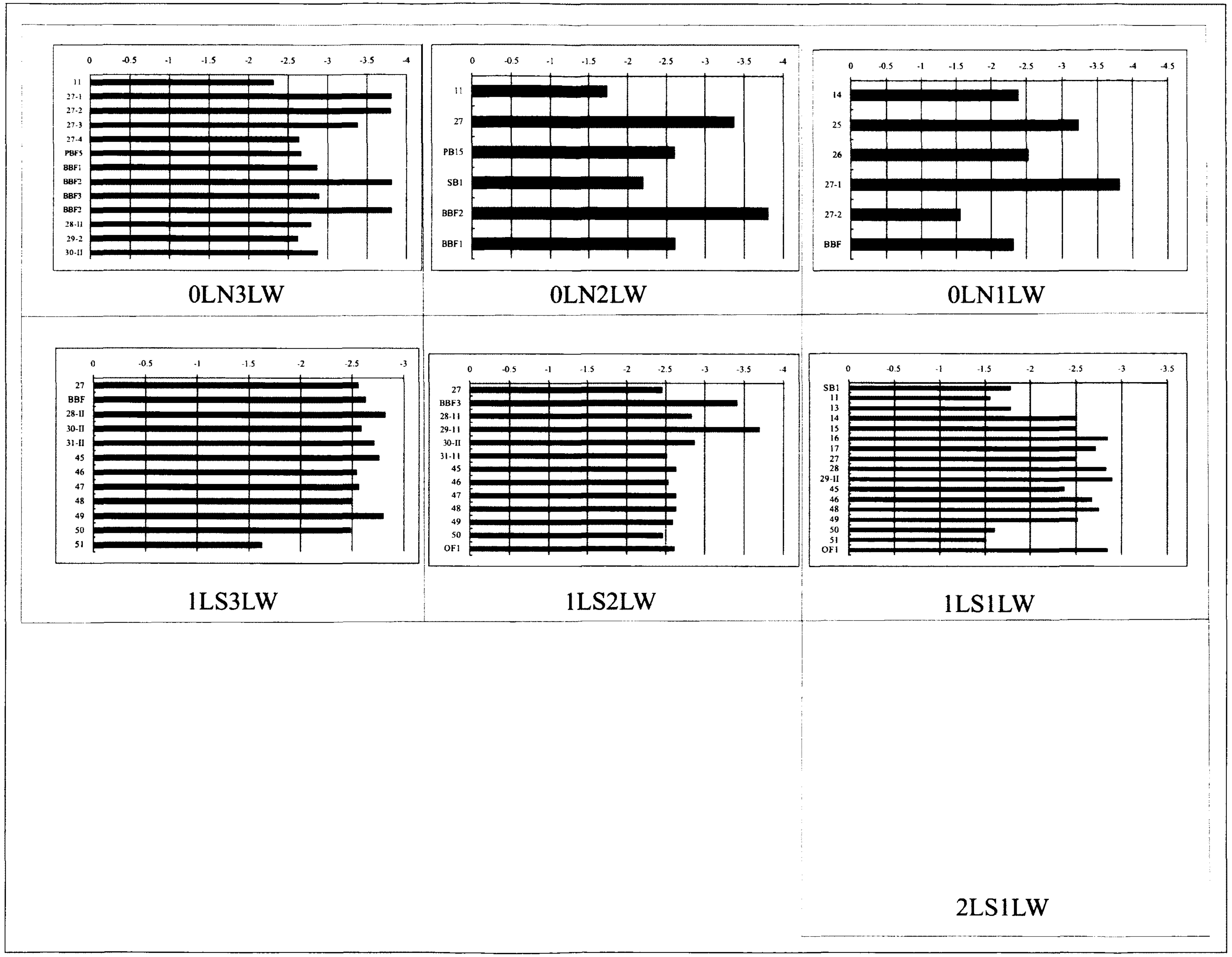

Figure 5.1 Water screened samples derived from units in the western half of the site. Each graph is depicted in its unit of origin within the site (the blank unit represents the lack of sample for this unit).

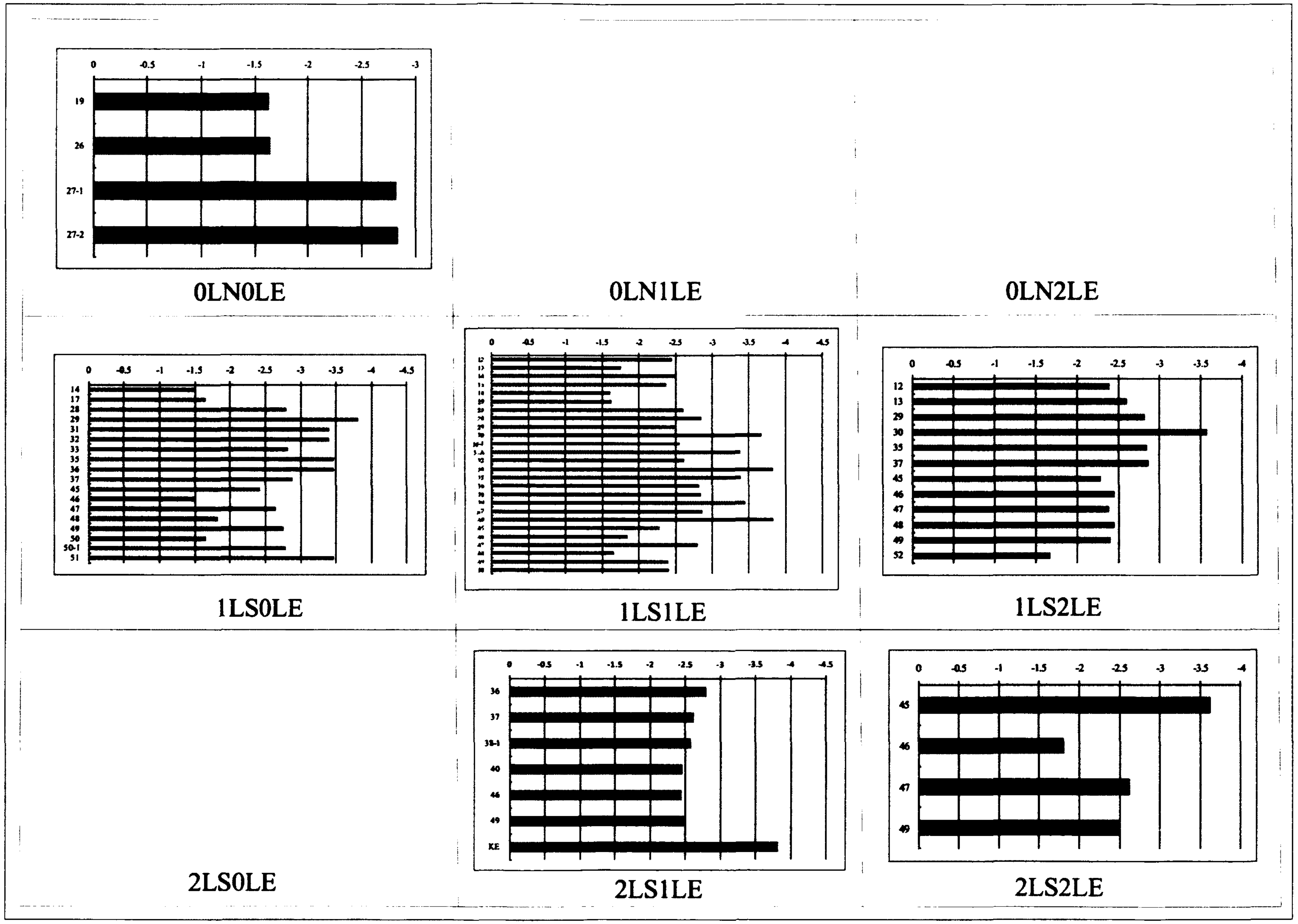

Figure 5.2 Water screened samples derived from unit in the eastern half of the site. Each graph is depicted in its unit of origin within the site (blank units represent the lack of samples for these units).

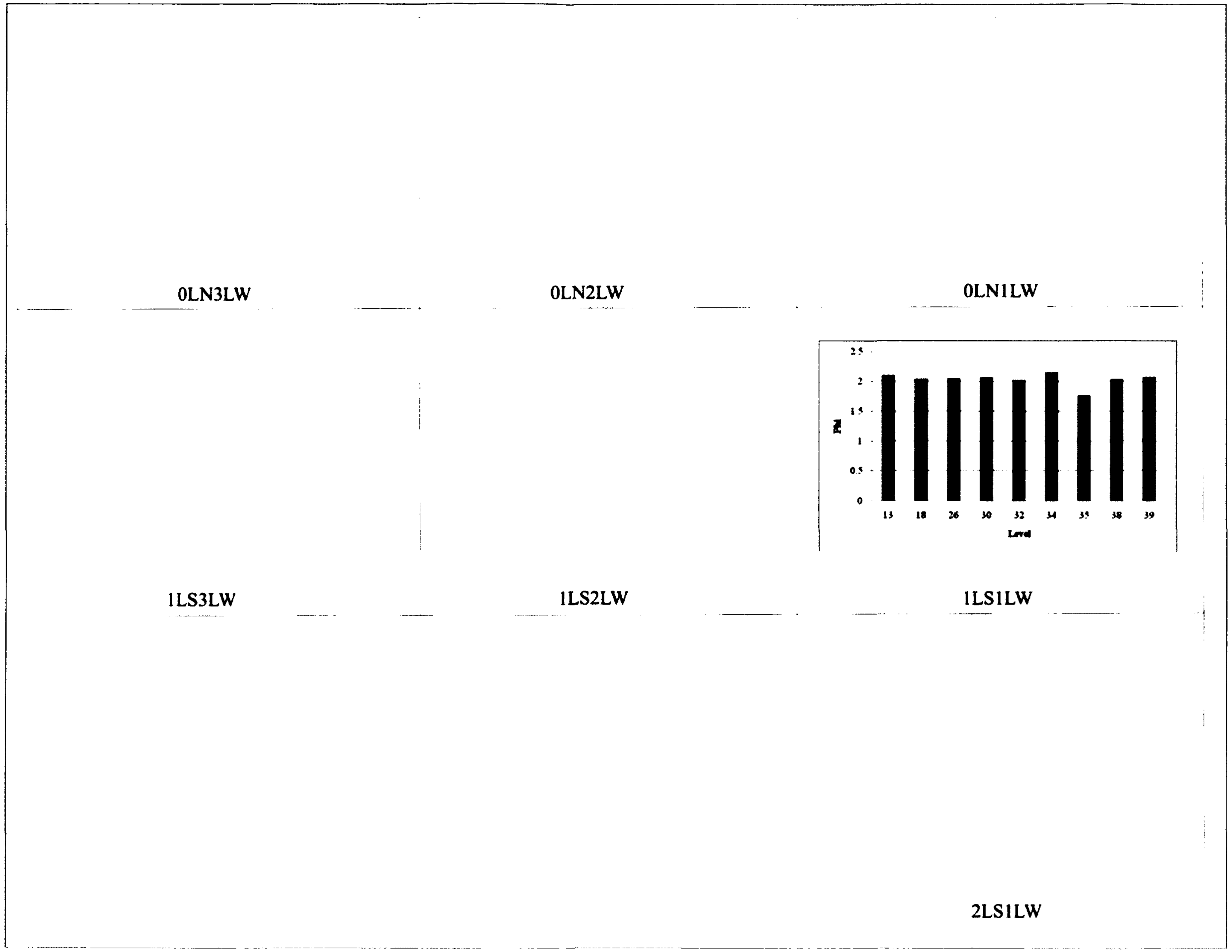

Figure 5.3 Bulk sample derived from unit in the western half of the site. The graph is depicted in its unit of origin within the site (blank units represent the lack of samples for these units).

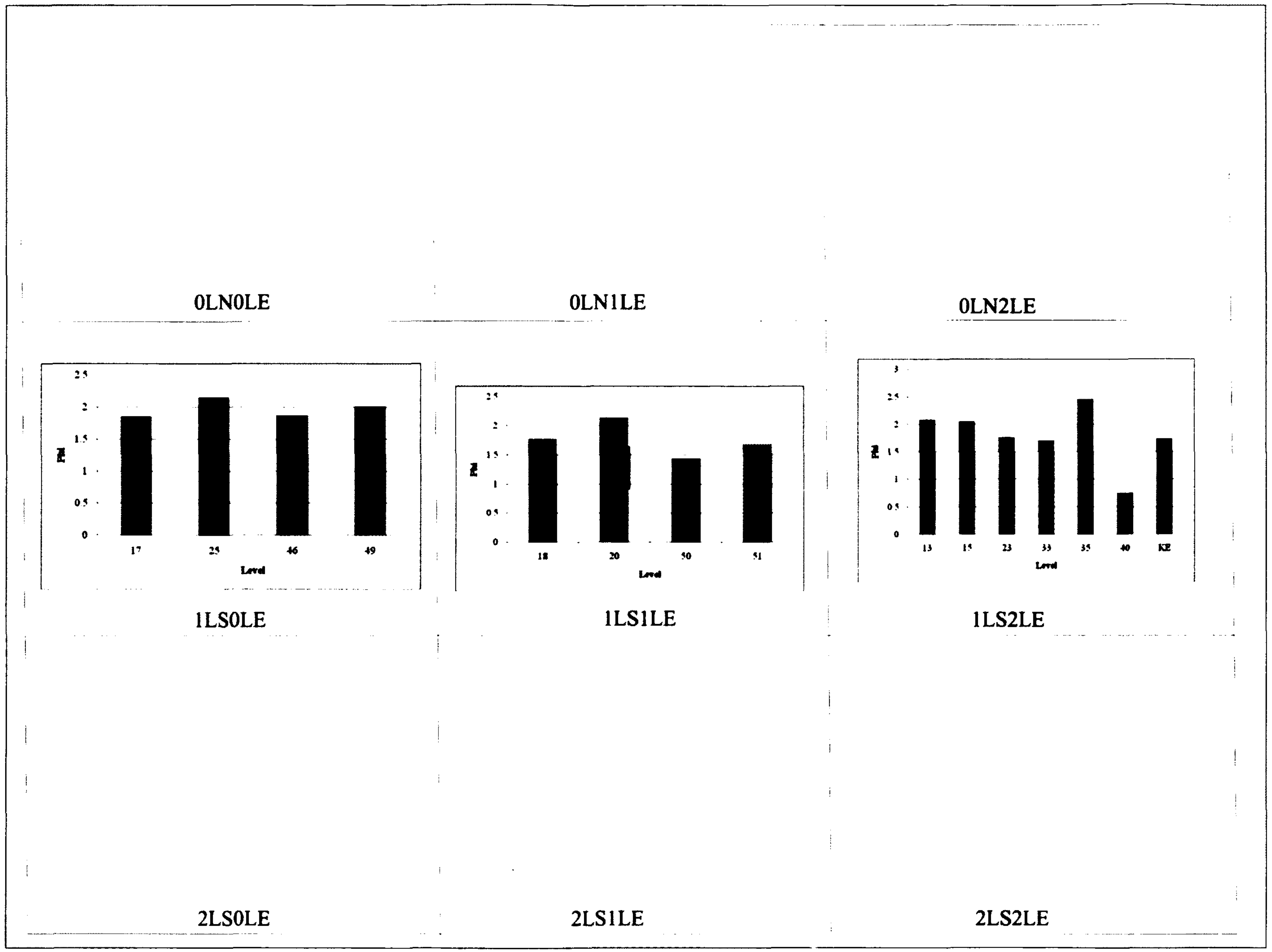

Figure 5.4 Bulk samples derived from units in the eastern half of the site. The graphs are depicted in their unit of origin within the site (blank units represent the lack of samples for these units).

5.8 Scanning Electron Microscopy of Selected Sediment Samples

Scanning electron microscopy was used to examine the surface textures of sediment grains to make further inferences about environment of deposition using surficial characteristics as illustrated by Krinsley and Marshall (1987) and Whalley and Krinsley (1974). The different textural characteristics of sediment grains provide a means by which to identify the environmental context of deposition. Relationships between surface textures and specific depositional environments have been established for aeolian, beach and glacial situations (Krinsley and Marshall 1987:2).

Samples were chosen based on their attributes as recorded in the level notes and because of their non-cultural context. Sediment samples from non-cultural contexts and from between living floors are likely to be more representative of local environmental conditions that those from living floors or other anthropogenic levels. So as to avoid observer bias, samples were identified using only the "So" (soil) number assigned to each one by the Park Service rather than specific provenience. After the samples were analyzed using the SEM, observations were compared with those recorded in the field notes for the level from which each sample was recovered.

5.8.1 Sample Pre-treatment

Samples were divided into sub-samples of 10 g each. These were pre-treated to remove organic material, carbonates, and soluble minerals whose presence would otherwise obscure observations of grain surfaces. Pre-treatment methods were based on those outlined by Bull et al. (1987), Day (1965), Gee and Bauder (1986), Kunze (1965), and Kunze and Dixon (1986). However, these methods were modified using only hydrochloric acid, hydrogen peroxide, and distilled/deionized water as not all chemicals were available.

Table 5.7 Samples Examined Under the SEM and Their Associated Levels and Radiocarbon Dates.

Sample No.	Associated Level	Associated Radiocarbon Date*
So 54	Dune	4180-4680±40 B.P.
So 37	15	5730±70 B.P.
So 72	18	5770±70 B.P.
So 94	20	
So 46	32	
So 122	39	ca. 5780±40 B.P.
So 131	40	5780±40 B.P.
So 159	51	ca. 6250-6300±40 B.P.
So 189	51	ca. 6250-6300±40 B.P.

***Dates from Schaaf 2002**

Each sample was placed in a beaker with 2N hydrochloric acid, enough to cover the sediments. Samples were left overnight to dissolve any carbonates. The 2N hydrochloric acid was decanted and a 30% hydrogen peroxide mix added. The samples were heated to a gentle boil for an hour after which they were left overnight to allow the complete breakdown of organic matter. The following day distilled/deionized water was added, the samples allowed to settle, and the excess hydrogen peroxide/water solution decanted. The samples were rinsed with distilled/deionized water and each one was placed in a small vial with distilled/deionized water and centrifuged for five minutes. This process was repeated three times to ensure that the chemicals were completely rinsed from the sediments and that all the soluable minerals were removed. The samples were then placed in an industrial oven to dry at 300° F for eight hours.

Following pre-treatment, small amounts of sediment from each sample were mounted on a specimen stub and made conductive by coating with a thin layer of gold in the ISI P-2 sputter coating unit. Samples are places in the specimen chamber where water and oxygen molecules are evacuated using a vacuum pump until the chamber reaches approximately 0.1 Pa. After oxygen (O_2) and water (H_2O) are removed argon (Ar) gas is pumped into the chamber and a negatively charged high voltage field between 18 and 20 mA is then applied to a gold electrode situated above the samples in the chamber. This procedure ionizes the argon gas molecules and converts them to Ar^+ and electrons (Bozzola and Russell 1999:67). The positively charged molecules bombard the negatively charged gold with such force that gold atoms are removed. These gold atoms then bounce off Ar^+ and electrons in the chamber until they hit the specimen, creating a coating of gold over the sample surface (Bozzola and Russell 1999:65). The random dispersion of the gold atoms ensures they will strike the specimen at different angles and create a uniform coating, even if the specimen is of an irregular shape (Bozzola and Russell 1999:67). Following preparation, individual samples were placed in the SEM and five grains from each sample were examined, with observations averaging about three hours for each sample. Observing multiple grains in each sample permits a more robust characterization.

Grain characteristics such as surface depressions, dents, smoothing, chemical alteration of the general structure, and the appearance of particles adhering to grain surfaces were recorded and photographed at magnifications between 150 X and 3000 X.

Each grain was also analyzed for mineral and elemental properties using the x-ray spectrometer attached to the microscope in an effort to determine grain compositions.

5.9 Grain Surface Characteristics and their Formation

Particle Adhesion is one of the most common surficial grain characteristics, wherein small silica particles adhere to the surface of the grain. This can come about from two different processes: 1) the adhering particles may break off from the grain itself and then be reincorporated while in a subaqueous environment; this mechanism is not well understood (Krinsley and Marshall 1987:5); or 2) precipitation platelets are created when silica is welded to the grain while it is in solution. Precipitation platelets are generally associated with supraglacial (on top of the glacier) environments. This results in grains that possess some of their pre-glacial deposition characteristics, as well as those generated by surficial glacial weathering (Whalley and Krinsley 1974:90). Precipitation refers to the dissolution of grains that are part of the sediment. After their dissolution, they move through interstitial voids in the deposit and are re-deposited when temperature and pressure conditions allow.

V-shaped Pits and Pitting are common surficial features. They are 'dents' in the surface of the grain that are characterized by a variety of wall and base shapes. V-shaped pits are created by chemical weathering of the grain surface. Surficial pitting can be created by mechanical weathering or by chemical weathering, whereby the surface of the grain is eroded leaving rounded pits (Krinsley and Doornkamp 1973; Whalley and Krinsley 1974).

Upturned plates are a "series of small plates protruding from the surface" of the grain. They are caused by chemical weathering of the grain (Whalley and Krinsley 1974:89). *Edge Rounding and Worn Surfaces* are sharp edges worn down by weathering, usually chemical. Edges and grain surfaces can also become rounded or smoothed by mechanical wear during aeolian movement. The latter is distinguished from chemical weathering by a surficial sheen associated with the area of wear.

5.10 Scanning Electron Microscope Observations

Beginning from the top of the profile, the first sediment sample, So 54, originates from the 2 m thick sand dune that caps the lower midden. The grains from this sample display a variety of textural surface features. Most common are pits that have rounded bottoms and V-shaped pits along with smaller silica particles adhering to grain surfaces. Grains three and five show [Figure 5.5 (1) and(3)] considerable mechanical fracturing, surface smoothing, and silica particle adhesion. Grains one and two [Figure 5.5 (2)] display extensive surface pitting and edge rounding which appears to be chemical in origin. The type of weathering on grain four is indeterminate; it is a piece of pyroclastic material - a tephra comprised of large circular vesicles, some with possible edge breakage, and some particle adherence.

Sample So 37 originates from level 15, a level containing shell, aeolian sand and tephra (see field notes, Appendix III). Surface textures were difficult to discern due to the considerable silica adhesion [Figure 5.6 (2)]. Visible areas display some V-shaped pits, and worn upturned plates that may result from chemical weathering, (Whalley and Krinsley 1974). Several pieces of pyroclastic material are identified as

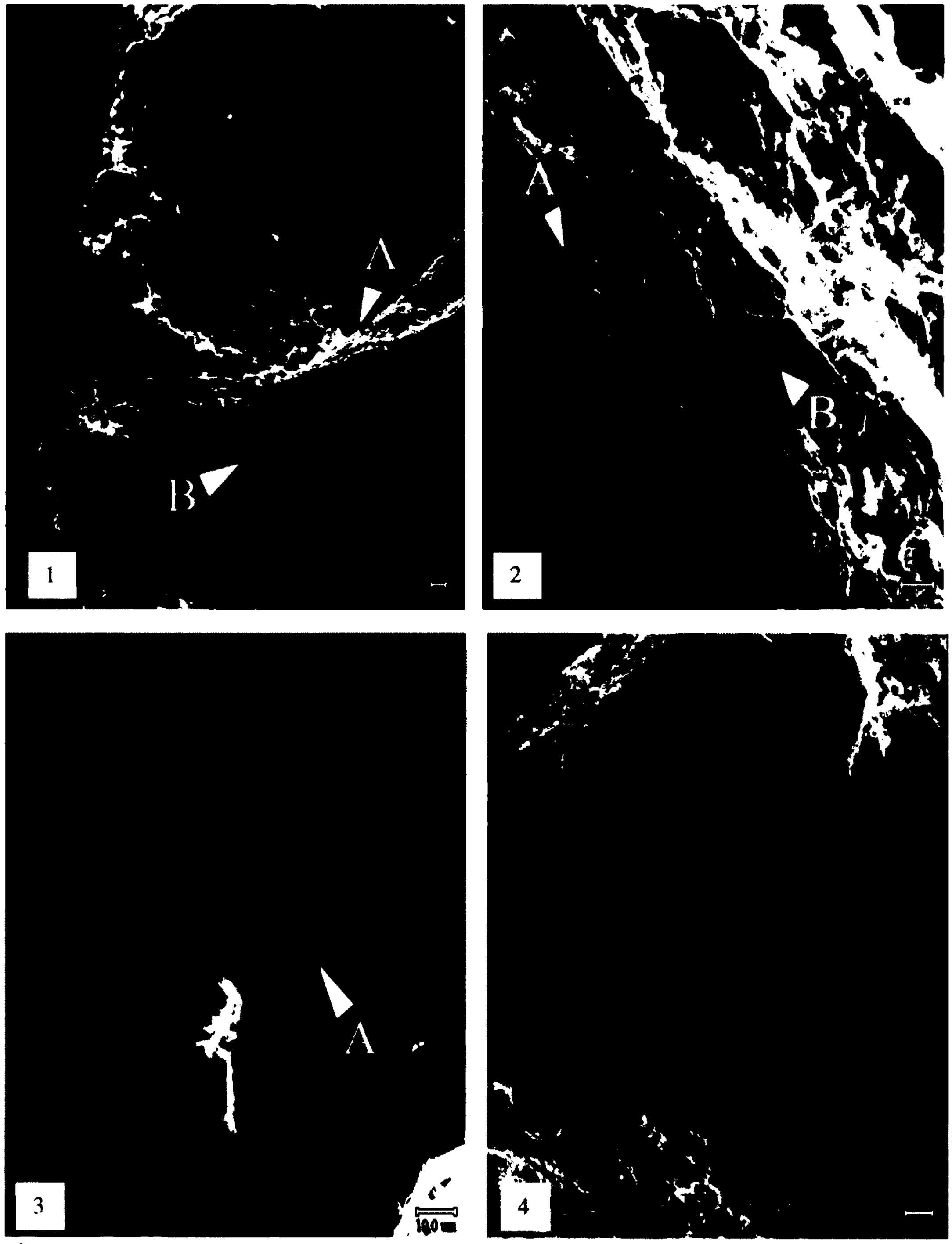

Figure 5.5 (1) Sample 54, example of rounded edges (A), and V-shaped pits (B) (S54g3); (2) Sample 45, example of particle adhesion (A) and pitting (B) (S45g1c); (3) Silica adhesion on sample grain (A) (S37g5a); (4) Tephra with crystal overgrowth (S37g4).

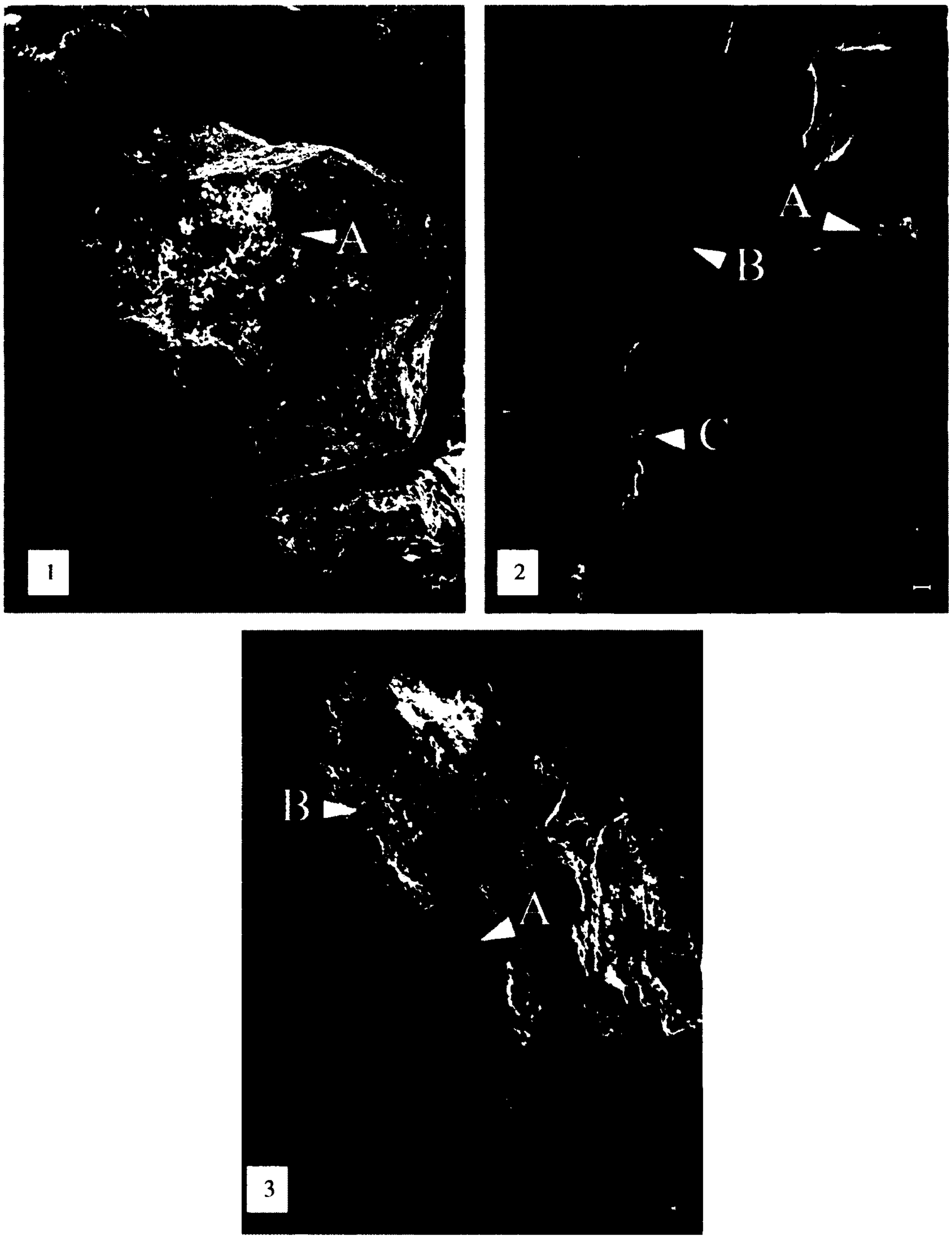

Figure 5.6 (1) Rounded sand grain with silica filled depressions (A) (S94g1); (2) Silica adhesion (A), upturned plates (B) and mechanical weathering (C) on tephra grain from level 51 (S159g2); (3) Edge rounding (A) and pitting (B) on a grain from level 51 (S189g3).

tephras, and there is pyroclastic material that has experienced crystal overgrowth (Figure 5.6) (Sheridan and Marshall 1987).

Sample So 72 originates from level 18 which is characterized as a mottled tephra and clay level (see field notes, Appendix III). However, clay particles were not discernable using the SEM. Grains two and three are pyroclastic grains and the remaining three are characterized by pitted surface textures with mechanically fractured upturned plates and considerable silica particle adhesion.

Sample 94 is associated with level 20 which is described as a tephra deposit underlying a red ochre floor (see field notes, Appendix III). Grain one is sand with rounded surfaces and depressions filled with silica particles [Figure 5.6 (1)]. Grain two is unidentifiable, exhibiting a platy texture, upturned plates, weathered/rounded edges, and surface pitting. The rounded edges, surficial pitting, and platy texture indicate chemical weathering. Three other grains are identified as tephra.

So 46 is from level 32 which was identified in the field as fill between two red ochre floors (see field notes, Appendix III). Grain one appears to be sand and displays a pitted surface texture, weathered and rounded step fractures, and silica particle adhesion. The weathering is chemical (via solution) implying a subaqueous or water influenced environment of deposition (Krinsley and Doornkamp 1973). Grains two, three, and four are pyroclastic particles and five may be a piece of microdebitage. It is little weathered, retaining sharp edges along its fracture scars. The scars are smooth and unaltered with the exception of silica grains adhering to the surfaces. The fractures on grain five are probably the result of mechanical fracture, likely caused by collision with other grains during movement, with little subsequent wear. Because the fracture scars are sharp, aeolian movement is likely.

Level 39 is located above the KE level and represents So 122. Grains one, two, and three are pieces of tephra. Grain four is also tephra, and displays smoothed surfaces with some surface pitting, upturned plates and silica deposition, suggesting chemical weathering. Grain five has little weathering with smooth surfaces and large flake scars created by mechanical weathering. There are silica particles adhering to its surfaces and small striations. The wear on all the grains from So 122 suggests both chemical and mechanical weathering.

Sample So 131 is from level 40 which is described as fill on top of the KE tephra level (see field notes, Appendix III). Four of the grains observed are pyroclastic material or tephra, supporting the field observations. Grain three is not of volcanic origin. It displays chemical and mechanical weathering, with chemically created pit and conchoidal fractures on both ends and particle adhesion.

So159 is from level 51, situated just above the OF2 occupation floor. The sample is characterized by pyroclastic grains; there are no mechanical fractures, upturned plates, chemical weathering, and silica particle adhesion [Figure 5.6 (2)], all of which would indicate chemical and mechanical alteration.

Sample So 189 originates from level 51, and contains grains that display a variety of mechanical and chemical weathering textures. All are covered by particles of silica, and appear to have some crystal overgrowth, edge rounding (Figure 5.6), and what may be deep etching. The wear on all suggests both chemical and mechanical weathering.

5.11 Petrographic Grain Analysis of Dune Sands

An interesting characteristic of the Mink Island deposit is the sand dune that caps the Lower Midden and separates it from the Upper Midden. It marks what may be a 2,000 year hiatus in occupation (Hilton 2002; Schaaf 2002). Grain size analysis in combination with radiometric dating provide important tools to determine how the sand dune was deposited, and in correlation with what, if any, regional environmental events (Table 5.8).

The radiometric dating regime at Mink Island was initially established by Hilton (2002:139) with a test pit placed in the Upper Midden that penetrated the sand dune and carried through into the top 14 cm of the Lower Midden. The dune deposit is 3.5 m below the surface and is 1.5 m thick (Hilton 2002:139).

Table 5.8 Radiocarbon Dates from Dune/Lower Midden Contact and the Upper Levels of the Lower Midden.

Depth	**Associated Level**	**Date and Beta Number**
41.5 cm BD	Surface of Lower Midden, Dune Contact	4680±40 BP (BC 3435 intercept) (Beta 130094)
43.5 cm BD (level 1)	Level 1, Lower Midden	4620±40 BP (BC 3225 intercept) (Beta 130109)
54 cm BD	Surface of Lower Midden, Dune Contact	4180±40 BP (BC 2795 intercept) (Beta 130095)
57-61 cm BD (level 2)	Level 2, Lower Midden	4420±30 BP (BC 3030 intercept) (Beta 130099)
62-71 cm BD (level 4)	Level 4, Lower Midden	3690±130 BP (BC 2095 intercept) (Beta 130102)
63-67 BD (level 3)	Level 3, Lower Midden	4450±30 BP (BC3095 intercept) (Beta 130100)
68 cm BD (level 1)	Level 1, Lower Midden	4520±40 BP (BC 3205 intercept) (Beta 130096)
71 cm BD (level 4 black surface)	Level 4, Lower Midden	4510±40 BP (BC 3180 intercept) (Beta 130101)
Unit 9 directly below sand*	Surface of Lower Midden, Dune Contact	4800±40 (BC 3635 intercept) (Beta 130087)

*** Date from Hilton 2002, all others from Schaaf 2002**

Mason (1998:17) first suggested that the sand capping the lower midden was aeolian in origin and offered three different possible sources:

1. It was generated by an increased period of storminess and a concomitant increase in storm waves;

2. A surplus of sand was deposited with the tephra from a volcanic eruption, or;

3. The dune resulted from an increase in sand supply brought on by the Little Ice Age (Mason 1998:19).

The Little Ice Age (LIA) hypothesis is immediately discounted due to the age range dates bracketing of the sand dune. The LIA spanned the period from 100 to 600 years ago, much later than the period of dune formation.

Aeolian deposition of the sand dune is suggested by the grain size analysis of the bulk material derived from this level however, the sample size of bulk material available for analysis from the dune level is very small, comprising only three samples, So 53, 54, and 63. The average grain size from all three samples is 1.5 Φ (0.35 mm), with two of the samples classified as gravelly sand, and one as sand. The two gravelly sand samples were also poorly sorted, and the sand sample, moderately well sorted. The average grain size falls within the size range possible for aeolian movement by saltation (Folk 1971), and the polymodal distribution of the two samples also suggest aeolian movement into the deposit (Ahrens et al. 2002; Folk 1971). Based on this minimal information, and the sand dune material examined during SEM analysis, it is very likely that the sand material was deposited via aeolian deposition, and not fluvial.

With an aeolian origin established for the dune sand, the question is what generated the surplus sand? To this end, Dr. Rainer Newberry (personal communication

2004) examined 500 grains of dune sand under thin-section and determined their mineral composition using x-ray diffraction. Only 1% of the deposit is volcanic glass, and 5% is tephra comprised of small aggregates of particles. The remainder is quartz, plagioclase feldspar, and possibly hornblende or fine-grained crystalline rock with abundant plagioclase phenocrysts. X-ray diffraction analysis identified quartz, plagioclase, and hornblende, but no potassium feldspars, pyroxene or biotite. Furthermore, the plagioclase particles exhibited no signs of weathering or clay alteration, while many of the grains contained inclusions of magnetite (Newberry personal communication 2004). Thus the bulk of the sand is derived from glacial erosion of parent rocks that has been re-transported as glacial sediments. These sediments are pieces of plutonic rock, either quartz diorite or tonalite that have undergone physical weathering but little chemical weathering (Newberry personal communication 2004). Diorite is a plutonic igneous rock that contains plagioclase feldspar and less than 40 percent hornblende, biotite and pyroxene or olivine, and it can contain small amounts of potassium feldspar, quartz and traces of magnetite, apatite, sphene and zircon (Banfield and Cook-Wallace 2002). "Diorite is the plutonic equivalent of the volcanic rock andesite...(and) occurs around margins of granitic batholiths, in separate plutons, and in dikes...It forms by the melting of rocks in the lower crust, by the assimilation of crustal rocks in basaltic magma, or as by metamorphic processes" (Banfield and Cook-Wallace 2002).

On the Alaska Peninsula, the Naknek Lake batholith, in the area of Lake Iliamna, is comprised of hornblende quartz diorite, hornblende-biotite quartz diorite, biotite-hornblende quartz diorite, and biotite quartz diorite (Wilson et al. 1999) (Figure 5.7).

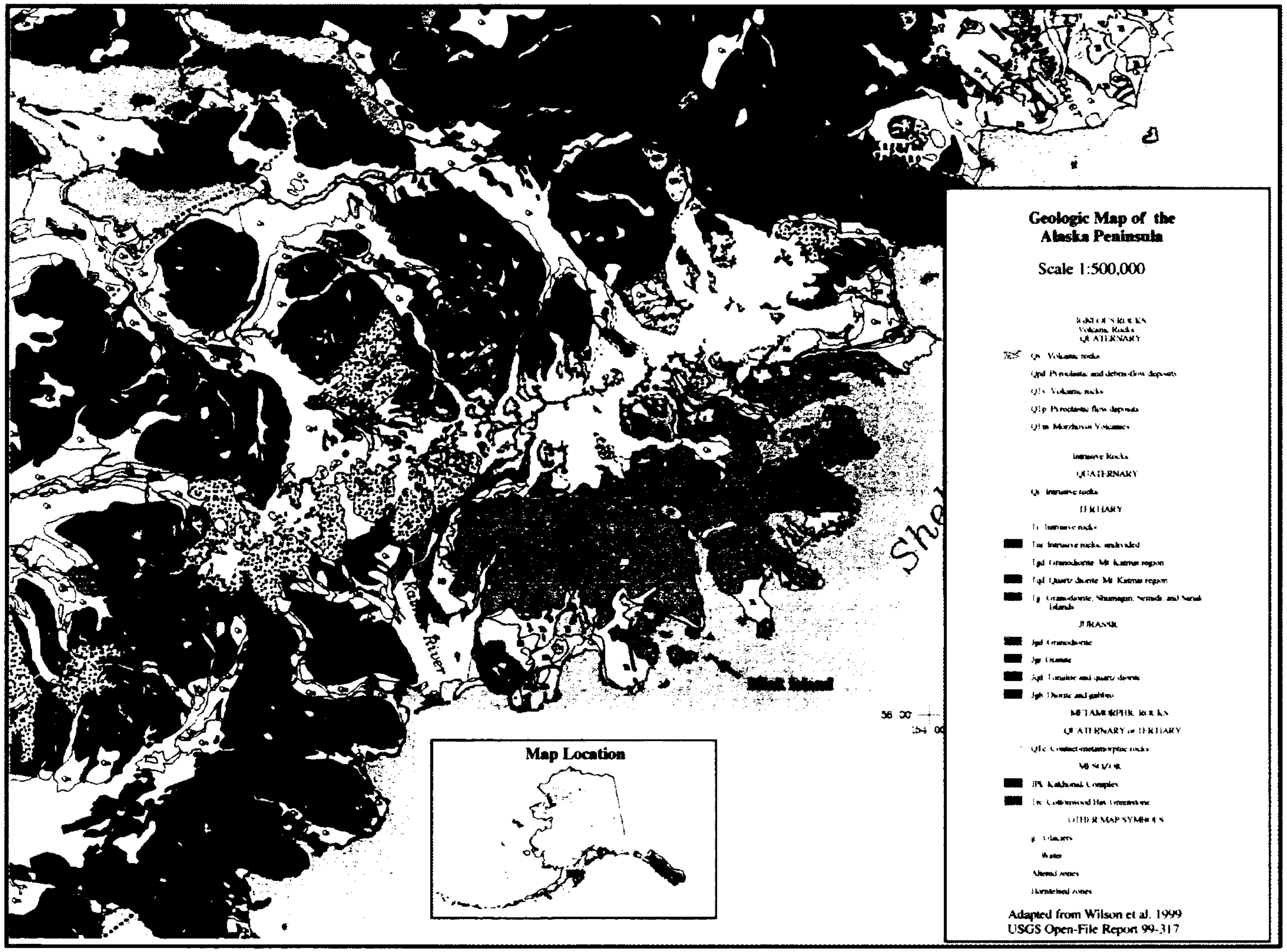

Figure 5.7 Geological Map of a portion of the Alaska Peninsula, adapted from Wilson et al. 1999

The sand dune could be comprised of glacially eroded volcanic batholiths from the mainland that were deposited via aeolian processes near the end of the Neoglacial (4000 and 2000 years ago) when temperatures were ameliorating. If so, it is possible that the glacier was situated on the Alaska Peninsula, and that the materials were derived from the Tertiary volcanic diorite and quartz-diorite deposits located in the areas of Naknek and Lake Iliamna (Wilson et al. 1999) and were deposited out of the glaciers as they receded. Currently, the glacial meltwater inputs 97 km^3 yr^{-1} in to the GOA (Weingartner 2007:18).

Conversely, the micromorphological analysis of the sediments indicated relatively little weathering of the feldspars, and suggested short distance aeolian and colluvial movement, indicating the sediments are derived from closer source than the central part of the Alaska Peninsula. It may be derived from the glacial moraine located in Amalik Bay, just north of Mink Island (Schaaf personal communication 2012) or from moraine sediments deposited nearby and brought into the site via aeolian and colluvial movement. However, this cannot be confirmed as the moraine material in Amalik Bay has not been geologically characterized.

Glacially derived materials were readily available during the period of dune deposition. In the Neoglacial, between ca. 4000 to 2000 B.P., the Hubbard, McCarty, Icy Bay and Bering glaciers experienced periods of expansion and contraction occurring around 2000 B.P. (Calkin et al. 2001; Mann et al. 1998:113). The advance of these glaciers was accompanied by increased storminess and precipitation and subsequent glacial erosion. Increased periods of storminess are indicated for northwest Alaska via proxy records (Mason and Jordan 1993), as well as in oxygen isotopes derived from sediments from Jellybean Lake in the Yukon, Canada (Anderson et al. 2005). Carbonate oxygen isotope analyses indicate that between 7500 and 4500 B.P. the Aleutian Low (AL) was weaker and/or more westward of its current location. Between 4500 and 3500 B.P., the AL was in a more eastward location and circulation intensified (Anderson et al. 2005:31) leading to an increase in coastal precipitation due to advection of warm moist air from the south to the northwest Pacific (Anderson et al. 2005:30).

In Alaska, these processes, in conjunction with tectonic and surficial processes, lead to the highest sediment yields in the world (Jaeger and Hallet 2005). The advance of glaciers may have increased sediment availability with an increase in meltwater, or surficial glacial sediments, or from glacial drift deposits, although more sediment is available just after glacial retreat because there are increased rates of sediment delivery into fluvial and aeolian systems (Benn and Evans 1998:261). This suggests then that the increased sediment availability is associated with periods of glacial contraction during the Neoglacial. Fluctuations in sea-level brought on by glacial expansion can also expose sediments, and generate a larger supply of local sand (Reineck and Singh 1980), thus the Neoglacial may have generally been a period of high availability of sediment from multiple sources.

5.12 Discussion

Scanning electron analysis indicates that most grains display attributes typically assigned to glacial material, with broken cleavage plates, conchoidal fractures, adhering particles, and upturned plates, and chemically weathered surfaces. Grains also possess features associated with diagenesis with particle filled cavities, and differential grain weathering (Krinsley and Doornkamp 1973; Krinsley and Marshall 1987:4; Whalley and Krinsley 1974:99). These observations are confirmed on the dune material (Newberry personal communication 2004) but cannot be entirely confirmed for the remaining sediments within the deposit.

Scanning electron analysis of sediments apart from the dune material, displayed both physical and chemical weathering. However, the majority of sediments appear to have been minimally impacted by either process. Considering this, along with the x-ray diffraction evidence, it is suggested that the Mink Island site sediments were originally deposited as glacial material near or on the site, and that they were subsequently reworked by both physical and chemical weathering processes but that physical processes dominated. It is also suggested that a contributing factor to the physical processes were successive human occupations of the site.

Chapter 6

Conclusions

6.1 Introduction

Site formation processes both create and disturb archaeological deposits. Perturbations created by human occupation and environmental events alter site deposit composition and structure. Archaeologists continue to make strides in identifying and understanding the effects of these processes on sites in a variety of environments. The GOA in particular poses an interesting problem in terms of our current understanding of formation processes in a highly dynamic environment. Few other locations in the world are subject to the same number of geologic (i.e. tectonics, volcanism, glacial activity) and atmospheric (i.e. fluctuations of the AL, the Pacific Decadal Oscillation, and El Niño) processes.

A number of different formation processes occurred at the Mink Island site, both cultural and non-cultural but only cursory links to environmental and geologic events within the broader GOA are possible. In the following pages I address the research questions posed at the beginning of my work, namely: **1)** Are there structural changes in the low midden deposits at Mink Island and if so, what do they look like? **2)** Do these structural changes indicate changes in depositional regimes throughout time, or was sediment deposition during abandonment governed by one process? **3)** Do the periods of site abandonment correlate with changes in depositional regimes and if so, do these changes indicate seasonal changes or do abandonment episodes correlated to larger regional environmental fluctuations? **4)** Do site deposits suggest changes in sea level throughout time, and the site's position relative to the shoreline? If so, are these reflected in the larger Gulf of Alaska?

Micromorphology, grain-size and SEM analyses are not the most appropriate analytical techniques to develop proxy climate data. This is not to say they are not applicable to archaeological analyses in general, or even in the GOA. They are however, ineffectual means by which to obtain data regarding *specific* environmental events, and cannot therefore, be used to extrapolate environmental drivers of human behavior. However, both micromorphology and grain size analysis are appropriate techniques to address the proposed research questions and both indicate that the two primary non-cultural formation processes on the site were aeolian and colluvial deposition.

6.2 Research Questions Answered

1. *Are there structural changes in the deposit and if so, what do they look like?*

There are changes in the deposit throughout time. These are illustrated by different void structures, the presence and absence of grain and void coatings, the presence, absence and appearance of nodules and cellular material, as well as different sediment color throughout the profile.

2. *Do these structural changes indicate changes in depositional regimes throughout time, or was sediment deposition during abandonment governed by one process?*

There do not appear to be widely divergent depositional regimes. Sediments within the site were likely deposited by aeolian and/or colluvial movement with secondary deposition during freezing temperatures likely during periods of winter abandonment. During occupation periods, sediments were likely derived from these same processes as well as material brought into the site by human occupants.

3. *Do the periods of site abandonment correlate with changes in depositional regimes and if so, do these changes indicate seasonal changes or do abandonment episodes correlate to larger regional environmental fluctuations?*

During periods of site abandonment colluvial movement and aeolian deposition are suggested. Occupation levels are associated with larger grain sizes and a greater abundance of organic material in the deposit (see field notes in Appendix III for a description of these sediments). The differences between abandonment and occupation levels are very distinct; humans clearly affected the means by which material accumulated in site deposits. Analysis suggests winter abandonment but beyond that, it is difficult to extrapolate additional seasonality data. This is however consistent with some of the data on seasonal seal hunting (Strathe 2008).

When the Mink Island data is compared to regional archaeological and environmental data, there are several interesting observations to be made. Long-term abandonment of the site and dune development dates ca. 4000 to 2000 B.P., during the Transitional Period from the Hypsithermal and the Neoglacial. There is a partial overlap here with a cultural hiatus in the Shelikof Strait between the Takli Birch (3500 to 2800 B.P.) and Takli Cottonwood (1800 to 1400 B.P.) Phases (Clark 1992a; 1998). There is also an occupational hiatus between the Brooks River Gravel Phase (3900 to 3000 B.P.) and the Smelt Creek Phase (2200 to 1800 B.P.) in the Naknek River drainage (Dumond 2011:115).

The Mink Island hiatus occurs between the LTI-3a and the LTI-3b zones of the Little Takli Island pollen profile. In the earlier portion of the profile, 3a, pollen frequencies are dominated by *Betula* and *Alnus* with increasing amounts of *Cyperaceae*, *Poaceae*, and *Sphagnum*. In the 3b zone (3600 to 2700 B.P.), there is an increase in *Ericales* and a decrease in Sphagnum and *Betula* and *Alnus* continue to dominate the landscape until 300 B.P. (Bigelow 2001). In essence a tundra landscape is present from about 3600 B.P. onward suggesting that there were no drastic environmental changes during the hiatus period.

Data from northwest Alaska indicate that area underwent periods of increased storminess associated with colder temperatures (Mason and Gerlach 1995; Mason and Jordan 1993). The years associated with cold temperatures and storms as well as warmer years are listed in Table 6.1. In that region is suggested that during years colder, stormier periods people move inshore earlier in the year (Mason and Gerlach 1995:105). At first

Table 6.1 Periods of Increased Storminess and Warmth and Associated Radiocarbon Dates.*

Associated Radiocarbon Dates	**Climate Type**
4000-3300 BP (2400-1600 BC)	Warm
3300-3000 BP (1600-1200 BC)	Cold, stormy
2000-1700 BP (100 BC-AD 300)	Cold, stormy
1700-1200 BP (AD 300-700)	Warm
1200-800 BP (AD 800-1050)	Cold, stormy

***from Mason and Gerlach 1995:106**

glance this appears to be a possible explanation for the abandonment of the site. More numerous and more intense storms could make navigation and exploitation of marine resources more difficult. However, the Mink Island abandonment dates cluster largely within the 4000 to 3000 B.P. range during a warm, less stormy of the neoglacial, making it difficult to discern of this was a likely a factor driving long-term site abandonment. There are no definitive storm deposits in the sediments analyzed here.

4. *Do site deposits suggest changes in sea level throughout time and the site's position relative to the shoreline? If so, are these reflected in the larger Gulf of Alaska?*

Mann and Crowell's (1998; Crowell and Mann 1996, 1998; Mann 2001; Mann et al. 1996) model of relative sea level along the coast of Katmai Park and the Alaska Peninsula is applicable to the Mink Island (XMK-030) site. There is no indication that the site was at any time inundated by the sea, suggesting that in the past it was further from the shore than it is at present. A drop in sea level and subsequent exposure of sand particles previously positioned in the surf zone just before 4000 years ago is suggested by the one and a half meters sand deposit capping the lower midden. It has only been within the last few hundred years that the lower portions of the site have been within reach of storm waves as sea level rose approximately 300 years ago, possibly due to tectonic activity (Crowell and Mann 1996; 1998; Mann and Crowell 1996).

6.3 Suggestions for Future Research

The data presented here suggest seasonal winter abandonment as do some of the faunal data examined by Strathe (2008). Zooarchaeological analysis of other species would shed further light on seasonality and provide additional lines of complementary evidence. Similarly, greater use of proxy climatological data generated through oceanography, geology, and volcanology provides additional lines of evidence on past local environment. We know that the climate in the GOA has been variable and fine-scale proxy data may provide information useful to explaining the archaeological record.

6.4 Conclusions

The results of this research have important implications for archaeological research. Micromorphology and grain size analysis allow insight into site seasonality, information which may not be readily discovered through other means (i.e., at sites where faunal preservation is lacking). Subsistence patterns along the Pacific coast of the Alaska Peninsula would have been affected if the outer coastal areas were not occupied during the winter months. This research also corroborates Mann and Crowell's (1996; 1998) sea level data for the Gulf of Alaska, suggesting that the sea level was much lower when the site was first established and that the current sea level is a relative recent occurrence.

Continued use of micromorphology in the field of archaeology promises to contribute a considerable data unavailable through other recovery techniques. As illustrated herein, it can aid in establishing site seasonality, identifying depositional processes and the environment of deposition. Micromorphology and grain size analysis provide a valuable avenue to describe and analyze site sediments and provide a useful tool by which to examine the validity of sediment descriptions made in the field by excavators.

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Appendix A

Photos of Micromorphology Slides

Figure A-1. Slide 1, vertical line at bottom indicates upward direction, double the original size.

Figure A-2. Slide 2, vertical line at bottom indicates upward direction, double the original size.

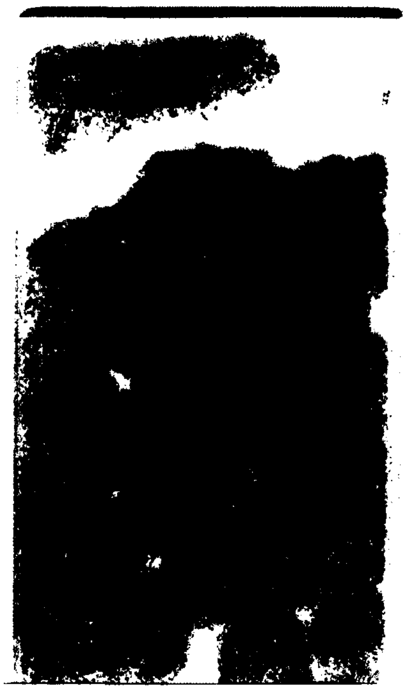


Figure A-3. Slide 3, vertical line at bottom indicates upward direction, double the original size.

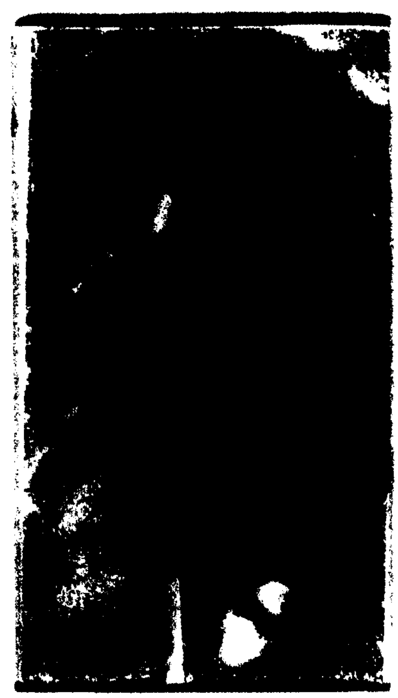


Figure A-4. Slide 4, vertical line at bottom indicates upward direction, double the original size.

Figure A-5. Slide 5, vertical line at bottom indicates upward direction, double the original size.

Figure A-6. Slide 6, vertical line at bottom indicates upward direction, double the original size.

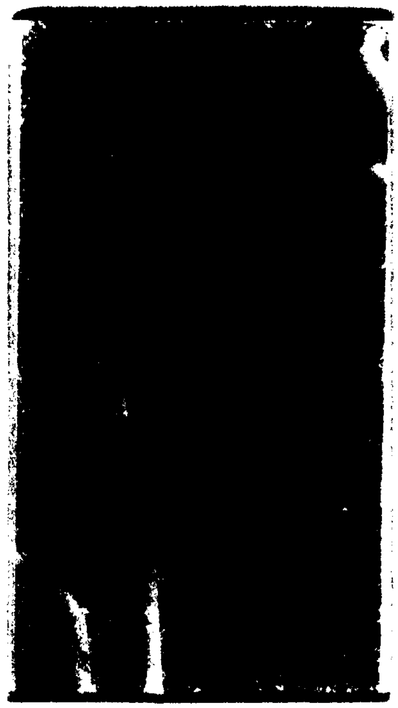


Figure A-7. Slide 7, vertical line at bottom indicates upward direction, double the original size.

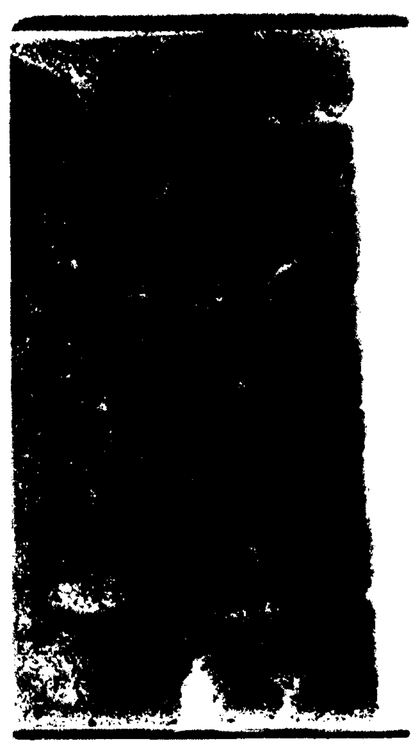


Figure A-8. Slide 8, vertical line at bottom indicates upward direction, double the original size.

Figure A-9. Slide 9, vertical line at bottom indicates upward direction, double the original size.

Figure A-10. Slide 10, vertical line at bottom indicates upward direction, double the original size.

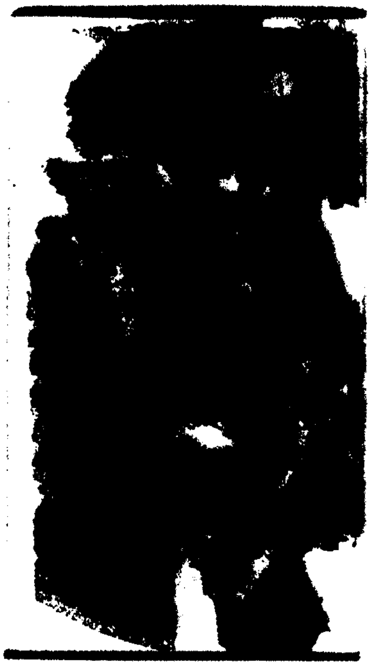


Figure A-11. Slide 11, vertical line at bottom indicates upward direction, double the original size.

Figure A-12. Slide 12,vertical line at bottom indicates upward direction, double the original size.

Figure A-13. Slide13, vertical line at bottom indicates upward direction, double the original size.

Figure A-14. Slide 14, vertical line at bottom indicates upward direction, double the original size.

Figure A-15. Slide 15, vertical line at bottom indicates upward direction, double the original size.

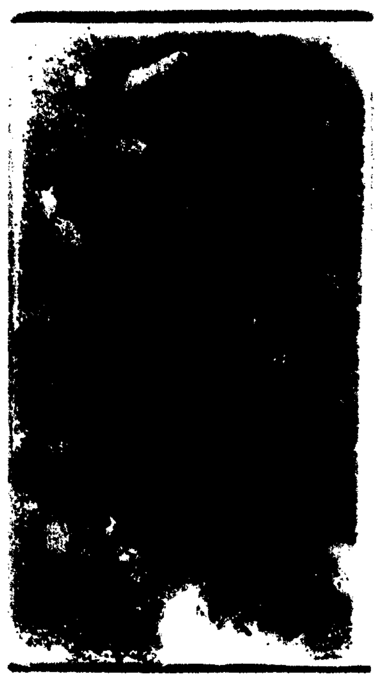
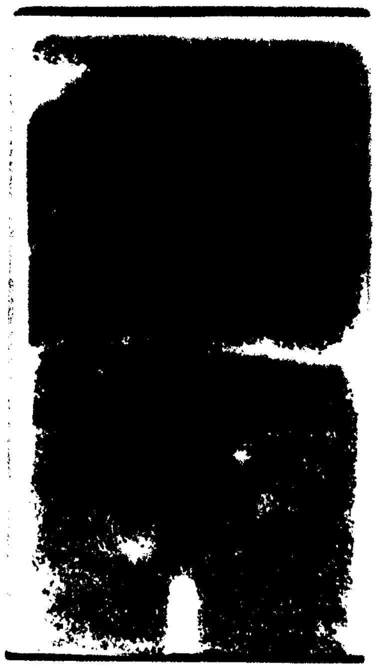


Figure A-16. Slide 16, vertical line at bottom indicates upward direction, double the original size.

Figure A-17. Slide 17, vertical line at bottom indicates upward direction, double the original size.

Figure A-18. Slide 18, vertical line at bottom indicates upward direction, double the original size.



Slide A-19. Slide 19, vertical line at bottom indicates upward direction, double the original size.

Figure A-20. Slide 20, vertical line at bottom indicates upward direction, double the original size.

Figure A-21. Slide 21, vertical line at bottom indicates upward direction, double the original size.

Appendix B

Microscopic Observations of each Slide from the Lower Midden

Table B-1.Summary of Micromorphological Features in the Lower Midden Sediment Profile.

Voids	Microstructure	C/f (limit; ratio, related distribution)	Coarse material (organic/mineral ratio)	Fine material (organic/mineral ratio)	Organic material	Pedofeature
lide 1 Complex packing Some channels (roots) 50% porosity	Complex blocky microstructure	5μm; 50/50;chitonic	10/90; Primary material is subrounded plagioclase feldspars; also have degrading mica, biotite, opaque minerals	50/50; Brown/black organics; black (opaque) iron minerals; stipple speckled b-fabric	Lignified tissue, plant residue	Amorphous pure nodules; infillings of loose discontinuous material, coatings on aggregates and channel walls, cappings on few aggregates
Slide 2 Simple packing; partially accommodating; narrow channels 40% porosity	Spongy; subangular blocky, moderate accommodation	5μm; 50/50; chitonic	30/70; Primary mineral is plagioclase feldspar, quartz, all weathered; rock material of schist and sandstone	80/20; brown organics, grey mineral, limpidity dotted; stipple speckle b-fabric	Lignified tissue; phlobaphene tissue; bone material	Monomorphic opaque with some polymorphic opaque features
Slide 3 Interaggregate voids; channel, compound and simple packing voids 50% porosity	Crumbly, angular subangular blocky aggregates	5μm; 25/75; close porphyric to chitonic	20/80; Plagioclase feldspar prevalent; quartz; biotite	5/95; brown/black organics, grey/yellow minerals, Stipple speckle b-fabric	Lignified tissue; spore	Typic amorphous nodules
Slide 4 Compound and chamber voids, found associated with organics; 40% porosity	Complex-crumbly/spongy; angular blocky peds	2μm; 50/50; close porphyric	20/80; Weathered feldspar; sandstone; quartz	70/30; black decaying organics; speckle b-fabric	Cellular; bone	Dusty clay features and typic amorphous nodules; organic staining

Table B-1.Summary of Micromorphological Features in the Lower Midden Sediment Profile, continued.

Voids	Microstructure	C/f (limit; ratio, related distribution)	Coarse material (organic/mineral ratio)	Fine material (organic/mineral ratio)	Organic material	Pedofeature
Slide 5 Complex packing voids; vertical orientation; 50% porosity	Crumbly/spongy;	2µm; 75/25; chitonic	2/98; weathered feldspar and quartz; schist; few conglomerates	60/40; brown organics; undifferentiated b-fabric	Phlobaphene and some cellular material	Typic amorphous nodules
Slide 6 Complex packing voids; upper portion highly compact	Crumbly/spongy; subangluar blocky aggregates; unaccommodating	1µm; 20/80; chitonic	90/10; Feldspar and quartz; with clay; possible hornblende and oxidization	50/50; brown organics, iron staining; stipple speckle b-fabric	Phlobaphene; small amount of bone	Amorphous nodule with brown coating; ferruginous feature; void coating
Slide 7 Vughy/compact; interaggregate voids50% porosity	Spongy; unaccommodating	2µm; 50/50; gefuric; moderately sorted	10/90; Feldspar; sandstone; schist; appears to be little coarse organics	90/10; brown organics, limpid, iron residue; stipple speckle b-fabric	Phlobaphene	Amorphous typic nodules that are opaque; monomorphic nodules; dark brown coatings
Slide 8 Channel and vugh voids, partially accommodating; fairly compact; 40% porosity	Spongy; some crumbly, angular blocky aggregates	2µm; 50/50; chitonic; loam like sand	50/50; Weathered feldspar and sandstone	90/10; brown/black organics; black iron or iron oxihydrates; some limpidity, speckled b-fabric	Cells; phlobaphene; likely root casts	Monomorphic black/brown nodules, likely iron or manganese
Slide 9 Vughs (2%); complex packing voids; 40% porosity	Spongy microstructure; subangular blocky aggregates	2µm; 50/50; chitonic; poorly sorted	100 coarse; Feldspar; mica and schist, all weathered	20/80; brown/black organics; dotted limpidity; speckled or dotted b-fabric	Phlobaphene	Typic amorphous nodules and monomorphic nodules that are ferruginous; fabric feature of dark brown/grey in void

Table B-1.Summary of Micromorphological Features in the Lower Midden Sediment Profile, continued.

Voids	Microstructure	C/f (limit; ratio, related distribution)	Coarse material (organic/mineral ratio)	Fine material (organic/mineral ratio)	Organic material	Pedofeature
Slide 10 Vughs and complex packing voids; 60% porosity	Spongy and crumbly microstructure with very coarse subangular aggregates	2μm; 40/60; enaulic; poorly sorted	20/80; weathered feldspars; mafic rocks	80/20; brown organic material; stipple speckle b-fabric	Phlobaphene; tissue cells; amorphous organic; orthic amorphous nodule with cellular; living floor material	Amorphous typic nodule of black; polymorphic, amorphous feature
Slide 11 Complex packing and vughs voids; base of slide compact; 50% porosity	Crumbly/granular/ Spongy microstructure; angular blocky aggregates	2μm; 60/40; chitonic; poorly sorted	30/70; feldspar; mafic rock	60/40; brown organics; speckle dotted b-fabric	Phlobaphene; cell residue; amorphous organic; bone fragment ; structural layers of black organics with cracking	Fabric pedofeature- laminar decayed organics associated with occupation
Slide 12 Complex, compound packing voids; unaccommodating; 50% porosity	Spongy/crumbly microstructure; subangular blocky aggregates	1μm; 50/50, chitonic to close porphyric; poorly sorted; sandy loam	10/90; feldspar; biotite; quartz; schist; conglomerates	90/10; brown organic material; organo-mineral material; stippled b-fabric	Phlobaphene; black decayed organic lenses; bone piece	Organic staining; amorphous typic black nodules; textural pedofeature of silty clay coating; iron coating on minerals
Slide 13 Complex packing voids and vughs; 60% porosity	Complex microstructure with crumbly and granular; angular blocky aggregates	2μm; 50/50; chitonic; poorly sorted	30/70; feldspars; quartz; conglomerates; schist	70/30; brown and black organics (decayed); brown staining on minerals; speckled b-fabric	Phlobaphene; punctuates associated with organic material of living floors; amorphous organic nodules	Fabric pedofeature of compaction; amorphous typic nodule of iron; silty-clay coatings on some voids and grains

Table B-1.Summary of Micromorphological Features in the Lower Midden Sediment Profile, continued.

Voids	Microstructure	C/f (limit; ratio, related distribution)	Coarse material (organic/mineral ratio)	Fine material (organic/mineral ratio)	Organic material	Pedofeature
Slide 14 Complex packing voids; smooth void walls; ultrafine to coarse voids; fairly compact; 50% porosity	Spongy to crumbly microstructure; angular coarse aggregates	2μm; 40/60; chitonic to enaulic; poorly sorted	10/90; plagioclase feldspar; quartz; biotite	80/20; brown and black organic material, also organic and ferruginous punctates	Tissue, decayed organic; root tissue	Compound pedofeature of iron with organic coating; amorphous typic ferruginous nodule; fabric pedofeature cracked black with silty clay coating
Slide 15 Complex packing voids and vughs; smooth to undulating walls; fairly compact; 50% porosity	Spongy microstructure; angular blocky aggregates	2μm; 30/70; close porphyric to chitonic; poorly sorted	100 coarse; quartz; feldspar; biotite; conglomerates	90/10; brown organics; black minerals (likely iron)	Phlobaphene; tissue with residue; root fragment	Compound pedofeatures of coating, amorphous typic nodule; amorphous typic polymorphic nodules
Slide 16 Complex packing voids and vughs; 50% porosity	Complex microstructure; subangular blocky aggregates; some spongy microstructure	2μm; 40/60; gefuric; poorly sorted	40/60; feldspar; quartz; biotite	50/50; brown and black organics; grey mineral material; Stipple speckle b-fabbric	Phlobaphene (black with red residue in cells); black decayed organics; three layers of decayed organic material; living floor; amorphous organic nodules	Textural features of void coatings; discontinuous infillings; amorphous typic nodules of ferruginous material

Table B-1.Summary of Micromorphological Features in the Lower Midden Sediment Profile, continued.

Voids	Microstructure	C/f (limit; ratio, related distribution)	Coarse material (organic/mineral ratio)	Fine material (organic/mineral ratio)	Organic material	Pedofeature
Slide 17 Complex packing voids and vughs; undulating; fairly compact; 40% porosity	Vughy to spongy microstructure	5μm; 50/50; closed porphyric; poorly sorted	30/70; plagioclase feldspar; biotite; quartz; highly weathered and altered	20/80; predominance of fine feldspar grains; brown organics; isotrophic under XPL; dotted /speckled b-fabric	Phlobaphene and parenchymatic tissue	Amorphous pseudomorph organic nodules and typic monomorphic and polymorphic ferruginous nodules
Slide 18 Complex packing voids and Vughs (50/50); undulating walls; slightly compact; 40% porosity	Vughy on top and single grains on bottom; subangular blocky on top and granular on bottom	10μm; 70/30; closed porphyric on top and monic on bottom; single grain structure; very poorly sorted	10/90; almost no organics; plagioclase feldspar; quartz; biotite; epidote; chlorite; highly altered/weathered minerals; mafic rock	10/90; almost no organic; minerals are grey and clayey; undifferentiated b-fabric; portion of the slide is missing fine material	None	Amorphous polymorphic typic nodules of manganese or iron; textural pedofeature of void coating
Slide 19 Channel and crumb voids; undulating walls; upper more compact than lower 50% porosity	Complex microstructure between crumby and granular; subangular blocky aggregates; five layers two occupation	5μm; 50/50; close porphyric; poorly sorted	20/80; plagioclase feldspar; iron or manganese; geotithe; quartz; biotite; sandstone	50/50; brown organics; grey and opaque (likely iron); speckled b-fabric	Organic residue some tissue residue and decayed organics associated with living floor	Amorphous pseudomorphic, polymorphic and monomorphic pedofeatures; opaque

Table B-1.Summary of Micromorphological Features in the Lower Midden Sediment Profile, continued.

Voids	Microstructure	C/f (limit; ratio, related distribution)	Coarse material (organic/mineral ratio)	Fine material (organic/mineral ratio)	Organic material	Pedofeature
Slide 20 Complex packing voids; undulating void walls; 50% porosity	Spongy/crumbly microstructure; four layers	5µm; 50/50; gefuric; poorly sorted	50/50; Plagioclase feldspar; biotite; muscovite; highly altered/weathered	60/40; dark brown organics; grey minerals; dotted limpidity; speckled b-fabric	Phlobaphene and parenchymatic organics; amorphous typic organic nodules	Amorphous pedofeatures monomorphic and polymorphic of iron oxides (manganese possibly)
Slide 21 Planar voids in upper portion of slide; complex packing in lower; 50% porosity	Complex microstructure; angular blocky Four layers; top closed porphyric, more compact, more fine organics Second less organics, large minerals chitonic Third more black decayed material, close porphyric Fourth less organics, large minerals; chitonic	5µm; 50/50; closed porphyric and chitonic; poorly sorted	100 mineral; Feldspar, quartz, biotite (feldspar most common)	60/40; organics darker upper slide, lighter lower slide; organics brown; grey black minerals; speckled b-fabric; dotted limpidity	Only fine grained organics; of decayed material, black	Inorganic iron residue; amorphous typic polymorphic nodules

Appendix C

Sediment Descriptions for Each Strata as

Described in Field Notes

Table C-1. Sediment Descriptions for Profile Levels.

Level	Munsell Color	Sediment Description
1	10YR2/2, 10YR3/2	Dark brown fine grained sand with pockets of grey sand, and silty clay grading to increased clay content with pea gravel, and flecks of charcoal as well as reddish brown sediments
2	10YR3/2, 10YR2/2, 7.5YR3/4	Very dark brown, sandy silt and clay with red mottled and very dark red silt, some charcoal present. Living floor/midden with charcoal, bone, shell, and flakes.
3	10YR2/2, 7.5YR3/4, 10YR2/2	Dark brown sandy, silty clay, pockets of tephra, with mottles of red and black sediments. Charcoal throughout and in association with midden feature in this level, also bone, shell and flakes.
4	10YR3/3, 10YR2/2	Level 4 is sandy silt that is dark yellowish brown, dark brown and dark reddish brown, with flecks of charcoal, some bone and shell material from the overlying midden. Pockets of tephra and clay. Level is fill overlying a black greasy floor.
5	10YR2/2	Dark brown sandy silt, dark reddish-brown clay and sand with lenses of charcoal and tephra, as well as some flakes, bone and shell.
6	10YR2/2, 7.5YR3/2, 7.5YR3/3, 5YR3/2	Brown to dark brown sandy silt and silty clay as well as clay with sand. Charcoal flecks throughout. Post mold associated with black surface in eastern units, shell, bone and flakes.
7	10YR2/2, 5YR3/2	Dark brown and dark reddish brown sandy silt and clay with pockets charcoal flecks in some units and tephra pockets. Black surface with basin feature, pit feature and patches of charcoal flecking, ochre staining and flakes and bone. Bone, cobbles and a core
8	10YR3/2, 10YR2/3	Dark brown sandy silty with charcoal, shell and bone. Charcoal concentration and black surface representing base of midden deposit. Also present are tephra pockets, red ochre staining, and a post mold.
9	10YR2/2, 5YR3/2, 10YR2/1, 10YR3/3	Dark brown sandy silt and red brown silt. Shell, bone and flakes present, lens of charcoal, ochre stained bone and tephra.
10	10YR2/2, 10YR3/2, 5YR3/2	Shell midden with alternating lenses of shell with dark brown sands and tephra. Very dark brown sandy silts, dark reddish brown clayey silts with pea gravel, beach pebbles and charcoal staining. Base of black sediments.
11	10YR2/2, 7.5YR2/0	Sandy silt fill, tephra, red ochre mottles over black charcoal surface with red ochre and bone. Shell midden with red ochre staining, charcoal, and ash. Dark reddish brown silty clayey sediments with dark oily matrix and red ochre, bone, pea gravel, pebbles and red ochre floor at base.
PBF-5/10	10YR3/2	Dark brown and black silty sand with charcoal over black greasy floor.
SB1	10YR3/2, 7.5YR4/6, 2.5YR3/6	Dark brown sandy loam with fine to medium-grain sand and tephra, red ochre staining from OF1 floor below.

Table C-1. Sediment Descriptions for Profile Levels, continued.

Level	Munsell Color	Sediment Description
OF1	2.5YR3/6, 2.5YR4/6, 5YR3/3, 10YR4/4, 2.5YR2.5/2, 7.5YR3/2, 7.5YR3/4	Red ochre stained clay and sand with tephra pockets. Over brown sand and silt fill.
12	10YR2/2, 10YR3/3	House floor, black charcoal sediments over tan sand and layer of tephra. Red ochre floor at base with dark red-brown silty sand, ash, charcoal, and gravel. . Brown sandy sediments outside house floor.
13	10YR2/2, 10YR3/3, 7.5YR3/2	Black charcoal surface with shell, sandy and bone. Black surface, toss zone adjacent to house floor and pits. Charcoal base covered by brown sand.
14	10YR3/6, 10YR3/2 (black), 10YR3/3, 7.5YR3/2	Shell midden, black surface with brown sand and bone, red ochre lined pit features present.
15	10YR3/3, 10YR3/4	Red ochre floor (OF1), black packed floor, bone dump of unconsolidated black greasy sediments and charcoal overlays it. Red ochre sandy loam with clay. Red brown silty clay with gravel, fill of shell, bone and flakes. Remnants of black floor, aeolian sand and KE tephra beneath.
16	7.5YR4/6, 5YR3/3 (ochre)	Midden over tephra layer. Clay with sand, tephra and flecks of clay.
17	10YR2/2, 10YR5/4 (tephra), 10YR7/2, 5YR3/2	Tephra, black layers under midden with bowl feature. Flakes, shell, silty sandy red-brown and brown sediments.
18	10YR2/2, 10YR5/3, 10YR2/1	Red ochre lens below shell, brown loose sandy silt, tephra layer with brown fine sand and organic material (redeposited) in basin depression. Silty clay and sand and black lenses and red ochre floor with tephra mottles.
19	2.5YR2.5/0, 2.5YR3/4, 2.5YR3/6 (red)	Black greasy, sandy loam under tephra, over red ochre floor. Fill of shell, bone, flakes, charcoal, ash and brow, red-brown sandy loam.
20	10YR2/2, 10YR4/3 (tephra), 10R3/4 (red ochre floor)	Red ochre floor, mottled tephra and sand, black staining. Culturally sterile layers of tephra and sand.
21	10YR2/2, 2.5YR3/2	Shell midden under brown loam and pockets of ash and sand. Midden matrix brown sandy loam. Black floor with ash mottles, charcoal, clayey sand, reddish sandy loam and red floor with tephra and shell midden.
22	7.5YR3/4	Red ochre floors, black organic lens dipping to the east, over brown fine sand with some shell with brown fill, over brown sandy clayey loam that overlies a thin black floor and part of a red floor. Clay and fine sand with rootlets and black organics also present.
23	10YR2/2, 2.5YR2.5/4, 2.5YR3/6	Shell midden with brown fill and mottled black sediments; black surface mottled with shell; red ochre floor with flakes. Red ochre floor clay, sand, with pockets of pebbles and cobbles. Lenses of red in a greasy silty, brown matrix.

Table C-1. Sediment Descriptions for Profile Levels, continued.

Level	Munsell Color	Sediment Description
24	5YR2.5/2	Shell midden with a black sticky matrix, and a fill of sandy-silt.
25	5YR3/3, 5Yr3/4	Shell midden, fill of mottled silty clayey sand, bone, brown sand sloping to east. Brown sand under red ochre floor and over black surface. Below shell midden mottled sandy clayey loam, mottled red and ash with charcoal fragments. Vertically oriented flakes along with fine sand and silt sediments that are yellowish brown.
26	10YR3/3, 10YR3/4	Greasy black sediment features with ash and ochre exposed. Brown, fine grained sand with decomposing rock and bone. Black surface has post molds filled with red stained tephra and sand. Raised black floor dipping to east, brown sandy-silty fill over floor. Midden feature, with silty sandy and brown clayey fill on top of a black floor. Fine to medium grained brown sand with pockets of bone and charcoal.
27-1	10YR2/2, 10YR3/4	Sub-floors above BBF floors. Charcoal stained silty clayey, pebbly sediments over fill of mottle dark brown clayey loam with find grained sand and bone.
27-2	10YR2/2, 7.5YR3/4, 2.5YR2.5/2, 10YR3/3	Sub-floor above BBF floors. Reddish-black floor of BBF partially exposed. Brown sandy sediment mottled with ash over BBF. Fill of dark brown very find sandy loam above pebbly black floor.
27-3/27-4	10YR3/3	Two sub-levels above BBF floor. Dark brown sandy loam with pockets of beach sand over a pebbly black floor.
BBF/BBF-1	7.5YR3/4, 10YR2.5/1, 5YR3/2	Several lenses of black greasy silty sandy with pebbles. Some sand lenses with lenses of densely packed debitage. Also present are black silt lamellae interspersed with dark reddish brown sand and dark reddish brown silty sand. Flakes and bone throughout.
BBF-2	10YR3/4, 5YR2.5/1, 7.5YR3/2, 5YR3/1, 5YR3/2	Black pebbly floor, greasy sand, silt, lenses of red silty sand and dark yellowish-brown fine sands. Highly decomposed bone and lithic material.
BBF-3	7.5YR3/4, 2.5YR2/0, 5YR3/2	Base of BBF, black greasy sediments with silt and very fine sand.
BBF-4	2.5Yr5/4, 5YR2.5/2	Two pebble features and a post mold, sediments of dark brown sand interspersed with brown sand, dark reddish brown sand and dark yellowish brown silt.
28-2	7.5YR3/4, 10YR3/3	Red floor with dark red brown silty clay and fine sand, hearth lined with pebbles, and a pit feature. Fill of silty clay with fine sand and bone.
29-2	7.5YR3/2, 10YR3/3, 10YR3/4, 10YR4/4	Black greasy organic sediments with bone and shell, a cobble feature, a basin feature, red ochre floor, and toss zone. Lenses of sand and fill of brown sand with silt.
30-2	10YR3/4, 10YR4/4, 5YR3/4, 5YR4/5	Cobble feature, red floor, red lens, basin feature, hearth feature filled with pebbles, and a post mold. Brown and red lenses with yellowish silts and sand. Sterile sediments appear aeolian, swirled sand and silt with charcoal and tephra. Sandy loam with charcoal and red ochre staining

Table C-1. Sediment Descriptions for Profile Levels, continued.

Level	Munsell Color	Sediment Description
31-2	10YR3/4, 10YR3/2	Three basin features, one filled with sandy loam, two sandy silt, charcoal flecks and pebbles. Red surface with brown mottling. Black silty sand lenses and heterogeneous marbled fill of silt, sand, fine sand and black silt.
32	5YR2.5/2, 10YR3/4, 7.5YR3/2	Black greasy floor with highly decomposed bone material, with crushed shell on top of it. Yellow-brown fill over red floor, top of next level.
33	5YR3/3, 5YR3/4	Greasy black floor, red ochre mottling, with bone, charcoal and crushed shell. Fill of shell, fine sand and clay of dark yellow as well as silty sand and clay with gravel and lens of shell and bone.
34	10YR3/4, 5YR3/3	Sterile level that follows red ochre stained deposits. Overlies sand and gravel layer above a midden of shell and bone. Basin feature filled with sand and shell. Brown fill with shell lens under this. Brown sandy silty fill over red ochre floor that has flecks of charcoal, all of which are above a black greasy silty floor with brown sandy fill. brown fill that underlies a shell lens. 1LSOLE contains fill that covers a red floor.
35	10YR4/4, 10YR6/4	Fill of sand and silt, highly decomposed bone material. Midden and lens of bone in level. Red ochre floor with tephra in areas as well as black greasy matrix, sandy silt fill with decomposed bone and flakes.
36	10YR4/3, 10YR3/4, 10YR3/6	Fill of brown yellowish sands with pockets of tephra. Shell midden over black greasy surface with bone.
37	10YR3/2, 10YR3/3, 10YR3/2, 10YR4/3	Fill of brown to dark brown sands with tephra. Anthropogenic black greasy sediments with bone and shell and ochre stained sediments.
38	10YR3/3, 10YR3/2, 7.5YR3/2, 5YR2.5/2	Hearth feature associated with debitage located under black sediments with fish bone. Several lenses of black compact sediments on top of brown fill that separates the hearth from the black floor in level 39. Brown fill of compact sand, mottled with charcoal and lithic debitage associated with a circular rock formation.
39	10YR3/3, 5YR2.5/1, 5YR3/2	Living floor associated with the hearth features in level 38. Level comprised of black sediments with bone and debitage lenses on top of the KE tephra.
40	10YR3/2, 7.5YR3/2, 7.5YR3/4	Fill of brown sand and silt with tephra directly on top of KE tephra level. Level also has black greasy floor with red ochre staining under level 39 hearth feature.
KE	10YR7/2 (KE), 10YR8/2, 5YR3/2	The KE tephra level. Post mold and a pebble filled feature. Flakes and bone material pressed onto the surface of KE and hearth on KE.

Table C-1. Sediment Descriptions for Profile Levels, continued.

Level	Munsell Color	Sediment Description
45	10YR3/2, 10YR3/3, 7.5YR3/4	Ochre stain with surface of wind or water scoured secondary deposit. Black sediments with tephra, bone and flakes feature. Basin feature filled with dark brown silt sand and KE tephra. Fill of brown silt and sand and dark reddish-brown sand with tephra.
46	2.5YR2.5/4, 2.5YR3/4, 10YR2/2, 5YR3/2, 10YR3/3	Basin feature, ochre stained sand and charcoal feature. Brown, reddish-brown silt and sand with pockets of gravel. Light yellowish-brown ochre stained sediments, and a marbled floor with lobes of sand, gravel, ash, and red ochre elsewhere. Secondary deposit of mottled loam with red and black stained sediments overlying red ochre levels that is base of site.
47	10YR3/3, 5YR3/2, 7.5YR3/4	Second of two red ochre floors, OF2. Also present are greasy black-grey sediments, and secondary deposits of mottled fill. Light yellowish-brown with red ochre staining of loam sediments, as well as brown and yellowish-brown sandy silt fill with red staining over OF2.
48	7.5YR3/2, 5YR3/3, 10YR3/2, 10YR3/4, 2.5YR4/4	Brown, light yellowish-brown, charcoal and ochre stained silt and sand over OF2 that appeared to be redeposited with some locations containing vertical flakes and charcoal. Two possible post mold features filled with sand and charcoal.
49	2.5YR4/4, 10YR3/2, 7.5YR2/0, 10YR3/3	OF2 being exposed. Three post molds. Fill of dark brown and yellowish-brown silt and clay. Greasy black sediments directly on top of OF2.
50	7.5YR3/2, 10YR3/3, 5YR2.5/1, 10YR4/2	OF2 continues to be exposed. Where not present fill of silty clay with pebbles, yellowish-brown mottle sand and silt with black streaking.
OF2		OF2 floor exposed. Post mold feature. OF2 underlain by brown sandy silt with thin black and red lenses.

Appendix D

Grain-Size Analysis Tables.

Table D-1. Grain-size Results for Bulk Sediments from Unit 1LS1LE.

Phi	**-5.5**	**-4.5**	**-3.5**	**-2.5**	**-1**	**-0.5**	**0**	**1.5**	**2.5**	**3.5**	**4.5**	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04-<**	
Sample # (Level)	**VCG$_1$**	**CG$_2$**	**MG$_3$**	**FG$_4$**	**VFG$_5$**	**VCS$_6$**	**CS$_7$**	**MS$_8$**	**FS$_9$**	**VFS$_{10}$**	**VCSilt-C$_{11}$**	**Textural Group**
10 (L13)	0	0	0	1.8	3.5	3.5	12.4	38.1	22.1	10.6	7.8	gravelly sand
37 (15)	0	0	0	1.8	0.9	4.5	18.2	38.2	18.2	9.1	9	slightly gravelly sand
184 (L23)	0	0	0	4.6	3.4	9.2	31	5.7	25.3	10.4	10.2	gravelly muddy sand
42 (L33)	0	0	0	0	8.8	10.5	18.4	28.9	15.8	8.8	9	gravelly sand
51 (L35)	0	0	0	1.5	1.5	1.5	11.4	35.6	22.7	11.4	14.4	slightly gravelly muddy sand
136 (L40)	0	0	0	0.6	26.7	19.9	11.8	16.8	11.2	5.6	7.2	gravelly muddy sand
159 (KE)	0	0	0	0	0	0.8	18.2	62.8	14	1.7	2.4	sand

Table D-2. Grain-size Results for Bulk Sediments from Unit 1LS2LE.

Phi	**-5.5**	**-4.5**	**-3.5**	**-2.5**	**-1**	**-0.5**	**0**	**1.5**	**2.5**	**3.5**	**4.5**	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04-<**	
Sample# (Level)	**VCG$_1$**	**CG$_2$**	**MG$_3$**	**FG$_4$**	**VFG$_5$**	**VCS$_6$**	**CS$_7$**	**MS$_8$**	**FS$_9$**	**VFS$_{10}$**	**VCSilt-C$_{11}$**	**Textural Group**
21 (L13)	0	0	0	2.6	0.9	2.6	14.7	41.4	19	9.5	9.6	slighly gravelly sand
85 (L18)	0	0	0	2.1	0.5	9.3	18.7	34.2	12.4	12.5	10.2	slightly gravelly muddy
249 (L26)	0	0	0	4.5	2.7	4.5	14.3	33.9	20.5	10.7	9	gravelly sand
34 (L30)	0	0	0	3.5	4.4	3.5	13.3	34.5	20.4	10.6	9.6	gravelly muddy sand
46 (L32)	0	0	0	5.5	1.8	3.6	20	34.5	15.5	8.2	10.8	gravelly muddy sand
68 (L34)	0	0	0	2.2	0	0	22.2	35.6	17.8	10	12	slightly gravelly muddy
76 (L35)	0	0	0	1.6	2.8	7.3	20.2	37.2	16.2	7.3	7.2	slightly gravelly sand
117 (L38)	0	0	0	3.8	0.5	8.5	16.9	31	18.8	11.3	9.6	slighly gravelly sand
122 (L39)	0	0	0	0	2.5	11.1	14.8	25.9	24.7	9.9	10.8	slightly gravelly sand

Table D-3. Grain-size Results for Bulk Sediments from Unit 1LS2LE.

Phi	**-5.5**	**-4.5**	**-3.5**	**-2.5**	**-1**	**-0.5**	**0**	**1.5**	**2.5**	**3.5**	**4.5**	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04-<**	
Sample# (Level)	**VCG$_1$**	**CG$_2$**	**MG$_3$**	**FG$_4$**	**VFG$_5$**	**VCS$_6$**	**CS$_7$**	**MS$_8$**	**FS$_9$**	**VFS$_{10}$**	**VCSilt-C$_{11}$**	**Textural Group**
72 (L18)	0	0	0	0.8	0	2.4	22.6	49.2	14.5	4.8	5.4	slightly gravelly sand
156 (L50)	0	0	0	2.6	4.3	12	23.1	33.3	13.7	6.8	4.2	gravelly sand
189 (L51)	0	0	0	0	1.7	7.7	24.8	42.7	14.5	3.4	5.4	slightly gravelly sand
94 (L20)	0	0	0	0	0.8	3.4	15.1	40.3	21	10.1	9	slightly gravelly sand

Table D-4. Grain-size Results for Bulk Sediments from Unit 1LS1LW.

Phi	**-5.5**	**-4.5**	**-3.5**	**-2.5**	**-1**	**-0.5**	**0**	**1.5**	**2.5**	**3.5**	**4.5**	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04-<**	
Sample# (Level)	**VCG$_1$**	**CG$_2$**	**MG$_3$**	**FG$_4$**	**VFG$_5$**	**VCS$_6$**	**CS$_7$**	**MS$_8$**	**FS$_9$**	**VFS$_{10}$**	**VCSilt-C$_{11}$**	**Textural Group**
73 (L17)	0	0	0	0.9	0.9	2.7	19.5	43.4	17.7	8	7.2	slightly gravelly sand
215 (L25)	0	0	0	2.5	2.5	2.5	16.1	32.2	20.3	11.9	12	gravelly muddy sand
113 (L46)	0	0	0	1.7	0.8	0.8	18.3	45.8	17.5	8.3	6.6	slightly gravelly sand
157 (L49)	0	0	0	0.9	1.8	5.5	19.3	39.4	15.6	8.3	6	slightly gravelly sand

Table D-5. Grain-size Results for Bulk Sediments from Unit 2LS1LE.

Phi	**-5.5**	**-4.5**	**-3.5**	**-2.5**	**-1**	**-0.5**	**0**	**1.5**	**2.5**	**3.5**	**4.5**	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04-<**	
Sample# (Level)	**VCG$_1$**	**CG$_2$**	**MG$_3$**	**FG$_4$**	**VFG$_5$**	**VCS$_6$**	**CS$_7$**	**MS$_8$**	**FS$_9$**	**VFS$_{10}$**	**VCSilt-C$_{11}$**	**Textural Group**
131 (L40)	0	0	0	1.6	1.6	2.3	16.3	45	17.8	7	8.4	Slightly gravelly sand
236 (LOF2)	0	0	0	1.7	4.1	7.4	24.8	31.4	14	9.1	7.2	gravelly sand
184 (L49)	0	0	0	4.6	3.4	9.2	31	5.7	25.3	10.4	10.2	gravelly muddy sand

Table D-6. Grain-size Results for Bulk Sediments from the Dune, No Associated Unit.

Phi	**-5.5**	**-4.5**	**-3.5**	**-2.5**	**-1**	**-0.5**	**0**	**1.5**	**2.5**	**3.5**	**4.5**	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04-<**	
Sample #	**VCG_1**	**CG_2**	**MG_3**	**FG_4**	**VFG_5**	**VCS_6**	**CS_7**	**MS_8**	**FS_9**	**VFS_{10}**	**VCSilt-C_{11}**	**Textural Group**
53	0	0	0	0	0	2.1	28.5	58.3	9	1.4	0.6	sand
54	0	0	0	0	5.8	15.8	30	19.2	10	15	4.2	gravelly sand
63	0	0	0	4.2	4.2	4.2	18.5	37	17.6	7.6	6.6	gravelly sand

Table D-7. Grain-size Results for Bulk Sediments from the Unit 0LN1LE.

Phi	**-5.5**	**-4.5**	**-3.5**	**-2.5**	**-1**	**-0.5**	**0**	**1.5**	**2.5**	**3.5**	**4.5**	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04-<**	
Sample# (Level)	**VCG_1**	**CG_2**	**MG_3**	**FG_4**	**VFG_5**	**VCS_6**	**CS_7**	**MS_8**	**FS_9**	**VFS_{10}**	**VCSilt-C_{11}**	**Textural Group**
41 (L15)	0	0	0	3.6	2.7	2.7	14.4	40.5	18.9	8.1	9	gravelly sand
198 (L21)	0	0	0	3.4	3.4	4.3	17.9	33.3	19.7	10.3	7.8	gravelly sand

Table D-8. Grain-size Results for Bulk Sediments from the Unit 0LN2LW.

Phi	**-5.5**	**-4.5**	**-3.5**	**-2.5**	**-1**	**-0.5**	**0**	**1.5**	**2.5**	**3.5**	**4.5**	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04-<**	
Sample# (Level)	**VCG_1**	**CG_2**	**MG_3**	**FG_4**	**VFG_5**	**VCS_6**	**CS_7**	**MS_8**	**FS_9**	**VFS_{10}**	**VCSilt-C_{11}**	**Textural Group**
6 (L27)	0	0	0	5.1	2.6	3.4	13.7	29.9	20.5	12	12.6	gravelly muddy sand
107 (PBF10)	0	0	0	2.6	2.6	5.3	20.2	39.5	15.8	7	7.2	gravelly sand

Table D-9. Grain-size Results for Bulk Sediments from the Unit 2LS2LE.

Phi	**-5.5**	**-4.5**	**-3.5**	**-2.5**	**-1**	**-0.5**	**0**	**1.5**	**2.5**	**3.5**	**4.5**	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04-<**	
Sample# (Level)	**VCG_1**	**CG_2**	**MG_3**	**FG_4**	**VFG_5**	**VCS_6**	**CS_7**	**MS_8**	**FS_9**	**VFS_{10}**	**VCSilt-C_{11}**	**Textural Group**
115 (L39)	0	0	0	0.8	4.1	7.4	19.8	38.8	15.7	7.4	6	slightly gravelly sand
112 (L38)	0	0	0	5.9	2.5	4.2	16.9	37.3	17.8	7.6	7.8	gravelly sand

Table D-10. Grain-size Results for Bulk Sediments from the Unit 0LN1LW.

Phi	**-5.5**	**-4.5**	**-3.5**	**-2.5**	**-1**	**-0.5**	**0**	**1.5**	**2.5**	**3.5**	**4.5**	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04-<**	
Sample# (Level)	**VCG_1**	**CG_2**	**MG_3**	**FG_4**	**VFG_5**	**VCS_6**	**CS_7**	**MS_8**	**FS_9**	**VFS_{10}**	**VCSilt-C_{11}**	**Textural Group**
63 (L16)	0	0	0	0	0	0	33.3	30.3	36.4	0	0	sand
1 (L27)	0	0	0	3.5	2.7	3.5	15.9	32.7	20.4	10.6	10.8	gravelly muddy sand

Table D-11. Grain-size Results for Bulk Sediments from the Unit 0LN3LW.

Phi	**-5.5**	**-4.5**	**-3.5**	**-2.5**	**-1**	**-0.5**	**0**	**1.5**	**2.5**	**3.5**	**4.5**	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04-<**	
Sample# (Level)	**VCG_1**	**CG_2**	**MG_3**	**FG_4**	**VFG_5**	**VCS_6**	**CS_7**	**MS_8**	**FS_9**	**VFS_{10}**	**VCSilt-C_{11}**	**Textural Group**
7 (L27-4)	0	0	0	5.7	2.5	2.5	12.3	32	20.5	11.5	13.2	gravelly muddy sand
5 (L27-3)	0	0	0	3.4	3.4	3.4	12.7	33.1	21.2	11.9	10.8	gravelly muddy sand

Table D-12. Grain-size Results for Bulk Sediments from the Unit 0LN0LE.

Phi	**-5.5**	**-4.5**	**-3.5**	**-2.5**	**-1**	**-0.5**	**0**	**1.5**	**2.5**	**3.5**	**4.5**	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04-<**	
Sample# (Level)	**VCG_1**	**CG_2**	**MG_3**	**FG_4**	**VFG_5**	**VCS_6**	**CS_7**	**MS_8**	**FS_9**	**VFS_{10}**	**VCSilt-C_{11}**	**Textural Group**
7 (L12)	0	0	0	0	0.8	7.4	24	42.1	14.9	5.8	4.8	slightly gravelly sand
12 (L27-2)	0	0	0	3.2	1.6	5.6	19	31.7	17.5	15.1	6.6	slightly gravelly sand

Table D-13. Grain-size Results for Bulk Sediments from the Unit 1LS2LW.

Phi	**-5.5**	**-4.5**	**-3.5**	**-2.5**	**-1**	**-0.5**	**0**	**1.5**	**2.5**	**3.5**	**4.5**	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04-<**	
Sample# (Level)	**VCG_1**	**CG_2**	**MG_3**	**FG_4**	**VFG_5**	**VCS_6**	**CS_7**	**MS_8**	**FS_9**	**VFS_{10}**	**VCSilt-C_{11}**	**Textural Group**
84 (L15)	0	0	0	2.2	1.5	2.9	16.1	38.7	19.7	10.2	9	slightly gravelly sand

Table D-14. Grain-size Results for Bulk Sediments from the Unit 0LN2LE.

Phi	**-5.5**	**-4.5**	**-3.5**	**-2.5**	**-1**	**-0.5**	**0**	**1.5**	**2.5**	**3.5**	**4.5**	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04-<**	
Sample# (Level)	**VCG_1**	**CG_2**	**MG_3**	**FG_4**	**VFG_5**	**VCS_6**	**CS_7**	**MS_8**	**FS_9**	**VFS_{10}**	**VCSilt-C_{11}**	**Textural Group**
203 (L24)	0	0	0	0	0	0	0	0	52.4	23.9	24	muddy sand

Table D-15. Grain-size Results for Water screened Sediments from the Unit 0LN2LW.

Phi	**-5.5**	**-4.5**	**-3.5**	**-2.5**	**-1**	**-0.5**	**0**	**1.5**	**2.5**	**3.5**	**4.5**	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04**	
Sample Level	**VCG_1**	**CG_2**	**MG_3**	**FG_4**	**VFG_5**	**VCS_6**	**CS_7**	**MS_8**	**FS_9**	**VFS_{10}**	**$VCSilt_{11}$**	**Textural Group**
11	0	0	35	33.8	0	31.2	0	0	0	0	0	sandy gravel
27-1	0	0	100	0	0	0	0	0	0	0	0	gravel
27-2	0	0	0	99.2	0.8	0	0	0	0	0	0	gravel
27-3	0	0	79.2	5.3	0	15.6	0	0	0	0	0	gravel
27-4	0	0	53.8	6.7	0	39.5	0	0	0	0	0	sandy gravel
PBF5	0	0	57	14.5	0	28.5	0	0	0	0	0	sandy gravel
BBF1	0	0	73.3	7.2	0	19.5	0	0	0	0	0	medium gravel
BBF2	0	0	88.4	2.9	0	8.7	0	0	0	0	0	gravel
BBF3	0	0	77.7	5.6	0	16.6	0	0	0	0	0	gravel
BBF2	0	0	88.4	2.9	0	8.7	0	0	0	0	0	gravel
28-II	0	0	61.1	11.1	0	27.9	0	0	0	0	0	sandy gravel
29-2	0	0	55	14	0	31	0	0	0	0	0	sandy gravel
30-II	0	0	73.7	7.6	0	18.7	0	0	0	0	0	gravel

Table D-16. Grain-size Results for Water screened Sediments from the Unit 1LS1LE.

Phi	**-5.5**	**-4.5**	**-3.5**	**-2.5**	**-1**	**-0.5**	**0**	**1.5**	**2.5**	**3.5**	**4.5**	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04**	
Sample	**VCG_1**	**CG_2**	**MG_3**	**FG_4**	**VFG_5**	**VCS_6**	**CS_7**	**MS_8**	**FS_9**	**VFS_{10}**	**$VCSilt_{11}$**	**Textural Group**
12	0	0	44.8	11.7	0	43.5	0	0	0	0	0	sandy gravel
13	0	0	33.1	16.9	0	50	0	0	0	0	0	sandy gravel
14	0	0	47.6	17.6	0	34.8	0	0	0	0	0	sandy gravel

Table D-17. Grain-size Results for Water screened Sediments from the Unit 1LS1LE, continued.

Phi	**-5.5**	**-4.5**	**-3.5**	**-2.5**	**-1**	**-0.5**	**0**	**1.5**	**2.5**	**3.5**	**4.5**	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04**	
Sample	**VCG_1**	**CG_2**	**MG_3**	**FG_4**	**VFG_5**	**VCS_6**	**CS_7**	**MS_8**	**FS_9**	**VFS_{10}**	**$VCSilt_{11}$**	**Textural Group**
14	0	0	47.6	17.6	0	34.8	0	0	0	0	0	sandy gravel
16	0	0	38.3	15.6	0	46.2	0	0	0	0	0	sandy gravel
18	0	0	23.6	19.3	0	57.2	0	0	0	0	0	sandy gravel
19	0	0	25.3	15.9	0	58.8	0	0	0	0	0	sandy gravel
23	0	0	54.2	14.2	0	31.6	0	0	0	0	0	sandy gravel
28	0	0	70.1	8.7	0	21.1	0	0	0	0	0	sandy gravel
29	0	0	46.7	12.7	0	40.6	0	0	0	0	0	sandy gravel
30	0	0	87.1	3.6	0	9.3	0	0	0	0	0	gravel
30-1	0	0	48.6	27.2	0	24.2	0	0	0	0	0	sandy gravel
31A	0	0	81.3	6.1	0	12.6	0	0	0	0	0	gravel
32	0	0	55.4	19	0	25.7	0	0	0	0	0	sandy gravel
34	0	0	100	0	0	0	0	0	0	0	0	moderate gravel
35	0	0	76.2	7.9	0	15.9	0	0	0	0	0	gravel
36	0	0	65.8	8.5	0	25.7	0	0	0	0	0	sandy gravel
38	0	0	70.7	8.9	0	20.5	0	0	0	0	0	sandy gravel
39	0	0	79.3	6.8	0	13.8	0	0	0	0	0	gravel
KE	0	0	75.2	5.4	0	19.4	0	0	0	0	0	gravel
40	0	0	100	0	0	0	0	0	0	0	0	moderate gravel
45	0	0	36.4	14.7	0	48.9	0	0	0	0	0	sandy gravel
46	0	0	36.5	13.5	0	50	0	0	0	0	0	sandy gravel
47	0	0	63.5	9.2	0	27.3	0	0	0	0	0	sandy gravel
48	0	0	27.8	16.2	0	56	0	0	0	0	0	sandy gravel
49	0	0	44.4	7.5	0	48.1	0	0	0	0	0	sandy gravel
50	0	0	44.9	10.1	0	45	0	0	0	0	0	sandy gravel

Table D-18. Grain-size Results for Water screened Sediments from the Unit 1LS1LW.

Phi	-5.5	-4.5	-3.5	-2.5	-1	-0.5	0	1.5	2.5	3.5	4.5	
Mm	42	22	11	5.5	2.8	1.4	1	0.44	0.17	0.08	0.04	
Sample	VCG_1	CG_2	MG_3	FG_4	VFG_5	VCS_6	CS_7	MS_8	FS_9	VFS_{10}	$VCSilt_{11}$	Textural Group
SB1	0	0	33.2	12.3	0	54.5	0	0	0	0	0	sandy gravel
11	0	0	19.8	20.2	0	60	0	0	0	0	0	sandy gravel
13	0	0	34.4	10.7	0	54.8	0	0	0	0	0	sandy gravel
14	0	0	46.6	13.5	0	39.9	0	0	0	0	0	sandy gravel
15	0	0	46.5	13.5	0	40	0	0	0	0	0	sandy gravel
16	0	0	71.8	7.1	0	21.1	0	0	0	0	0	sandy gravel
17	0	0	56.8	8	0	35.3	0	0	0	0	0	sandy gravel
27	0	0	45.2	18.4	0	36.4	0	0	0	0	0	sandy gravel
28	0	0	65.8	9.4	0	24.8	0	0	0	0	0	sandy gravel
29-II	0	0	79.1	4.4	0	16.4	0	0	0	0	0	gravel
45	0	0	40.7	10.9	0	48.4	0	0	0	0	0	sandy gravel
46	0	0	56.9	10.9	0	32.3	0	0	0	0	0	sandy gravel
48	0	0	60.4	13.3	0	26.3	0	0	0	0	0	sandy gravel
49	0	0	47.4	16	0	36.6	0	0	0	0	0	sandy gravel
50	0	0	26.5	13.5	0	60	0	0	0	0	0	sandy gravel
51	0	0	18.6	17.3	0	64.1	0	0	0	0	0	sandy gravel
OF1	0	0	70.7	8.1	0	21.2	0	0	0	0	0	sandy gravel

Table D-19. Grain-size Results for Water screened Sediments from the Unit 0LN0LE.

Phi	-5.5	-4.5	-3.5	-2.5	-1	-0.5	0	1.5	2.5	3.5	4.5	
Mm	42	22	11	5.5	2.8	1.4	1	0.44	0.17	0.08	0.04	
Sample	VCG_1	CG_2	MG_3	FG_4	VFG_5	VCS_6	CS_7	MS_8	FS_9	VFS_{10}	$VCSilt_{11}$	Textural Group
19	0	0	26.4	13.4	0	60.2	0	0	0	0	0	sandy gravel

Table D-19. Grain-size Results for Water screened Sediments from the Unit 0LN0LE, continued.

Phi	-5.5	-4.5	-3.5	-2.5	-1	-0.5	0	1.5	2.5	3.5	4.5	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04**	
Sample	**VCG_1**	**CG_2**	**MG_3**	**FG_4**	**VFG_5**	**VCS_6**	**CS_7**	**MS_8**	**FS_9**	**VFS_{10}**	**$VCSilt_{11}$**	**Textural Group**
26	0	0	24.7	23.4	0	51.9	0	0	0	0	0	sandy gravel
27-1	0	0	66.7	6.9	0	26.4	0	0	0	0	0	sandy gravel
27-2	0	0	67.8	8.6	0	23.6	0	0	0	0	0	sandy gravel

Table D-21. Grain-size Results for Water screened Sediments from the Unit 2LS2LE.

Phi	-5.5	-4.5	-3.5	-2.5	-1	-0.5	0	1.5	2.5	3.5	4.5	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04**	
Sample	**VCG_1**	**CG_2**	**MG_3**	**FG_4**	**VFG_5**	**VCS_6**	**CS_7**	**MS_8**	**FS_9**	**VFS_{10}**	**$VCSilt_{11}$**	**Textural Group**
45	0	0	85.5	4.5	0	10	0	0	0	0	0	gravel
46	0	0	31.6	16.1	0	52.4	0	0	0	0	0	sandy gravel
47	0	0	54.9	12.4	0	32.7	0	0	0	0	0	sandy gravel
49	0	0	47	13.4	0	39.7	0	0	0	0	0	sandy gravel

Table D-22. Grain-size Results for Water screened Sediments from the Unit 1LS2LE.

Phi	-5.5	-4.5	-3.5	-2.5	-1	-0.5	0	1.5	2.5	3.5	4.5	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04**	
Sample	**VCG_1**	**CG_2**	**MG_3**	**FG_4**	**VFG_5**	**VCS_6**	**CS_7**	**MS_8**	**FS_9**	**VFS_{10}**	**$VCSilt_{11}$**	**Textural Group**
12	0	0	43.7	14.2	0	42.1	0	0	0	0	0	sandy gravel
13	0	0	55.6	11.2	0	33.2	0	0	0	0	0	sandy gravel
29	0	0	64.5	9	0	26.5	0	0	0	0	0	sandy gravel
30	0	0	84.7	6.6	0	8.7	0	0	0	0	0	gravel

Table D-23. Grain-size Results for Water screened Sediments from the Unit 1LS2LE, continued.

Phi	**-5.5**	**-4.5**	**-3.5**	**-2.5**	**-1**	**-0.5**	**0**	**1.5**	**2.5**	**3.5**	**4.5**	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04**	
Sample	**VCG_1**	**CG_2**	**MG_3**	**FG_4**	**VFG_5**	**VCS_6**	**CS_7**	**MS_8**	**FS_9**	**VFS_{10}**	**$VCSilt_{11}$**	**Textural Group**
35	0	0	69.7	9.5	0	20.8	0	0	0	0	0	sandy gravel
37	0	0	73.2	6.7	0	20	0	0	0	0	0	sandy gravel
45	0	0	33	22.5	0	44.5	0	0	0	0	0	sandy gravel
46	0	0	42.6	19.3	0	38.1	0	0	0	0	0	sandy gravel
47	0	0	40.8	15.9	0	43.3	0	0	0	0	0	sandy gravel
48	0	0	46.8	11	0	42.2	0	0	0	0	0	sandy gravel
49	0	0	45.7	8.4	0	45.8	0	0	0	0	0	sandy gravel
52	0	0	31	17.4	110	51.6	0	0	0	0	0	sandy gravel

Table D-24. Grain-size Results for Water screened Sediments from the Unit 0LN1LW.

Phi	**-5.5**	**-4.5**	**-3.5**	**-2.5**	**-1**	**-0.5**	**0**	**1.5**	**2.5**	**3.5**	**4.5**	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04**	
Sample	**VCG_1**	**CG_2**	**MG_3**	**FG_4**	**VFG_5**	**VCS_6**	**CS_7**	**MS_8**	**FS_9**	**VFS_{10}**	**$VCSilt_{11}$**	**Textural Group**
14	0	0	39.2	15.3	0	45.5	0	0	0	0	0	sandy gravel
25	0	0	77.9	10.4	0	11.6	0	0	0	0	0	gravel
26	0	0	47.7	17.9	0	34.4	0	0	0	0	0	sandy gravel
27-1	0	0	100	0	0	0	0	0	0	0	0	gravel
27-2	0	0	21.1	11.7	0	67.2	0	0	0	0	0	sandy gravel
BBF	0	0	41.1	11.4	0	47.5	0	0	0	0	0	sandy gravel

Table D-25. Grain-size Results for Water screened Sediments from the Unit 0LN2LW.

Phi	-5.5	-4.5	-3.5	-2.5	-1	-0.5	0	1.5	2.5	3.5	4.5	
Mm	42	22	11	5.5	2.8	1.4	1	0.44	0.17	0.08	0.04	
Sample	VCG_1	CG_2	MG_3	FG_4	VFG_5	VCS_6	CS_7	MS_8	FS_9	VFS_{10}	$VCSilt_{11}$	Textural Group
11	0	0	30.7	19.3	0	50	0	0	0	0	0	sandy gravel
27	0	0	76	8.3	0	15.6	0	0	0	0	0	gravel
PB15	0	0	54	13.5	0	32.5	0	0	0	0	0	sandy gravel
SB1	0	0	27.9	26	0	46.2	0	0	0	0	0	sandy gravel
BBF2	0	0	89.4	2.7	0	7.9	0	0	0	0	0	gravel
BBF1	0	0	54.2	12.5	0	33.3	0	0	0	0	0	sandy gravel

Table D-26. Grain-size Results for Water screened Sediments from the Unit 1LS0LE.

Phi	-5.5	-4.5	-3.5	-2.5	-1	-0.5	0	1.5	2.5	3.5	4.5	
Mm	42	22	11	5.5	2.8	1.4	1	0.44	0.17	0.08	0.04	
Sample	VCG_1	CG_2	MG_3	FG_4	VFG_5	VCS_6	CS_7	MS_8	FS_9	VFS_{10}	$VCSilt_{11}$	Textural Group
14	0	0	18	17.4	0	64.5	0	0	0	0	0	sandy gravel
17	0	0	24.3	23.5	0	52.2	0	0	0	0	0	sandy gravel
28	0	0	62.4	8.4	0	29.2	0	0	0	0	0	sandy gravel
29	0	0	88.9	2.8	0	8.3	0	0	0	0	0	gravel
31	0	0	71.7	17.7	0	10.6	0	0	0	0	0	gravel
32	0	0	68.4	19.8	0	11.8	0	0	0	0	0	gravel
33	0	0	68.2	8	0	23.8	0	0	0	0	0	sandy gravel
35	0	0	81.1	5.3	0	13.6	0	0	0	0	0	gravel
36	0	0	80.3	6.9	0	12.8	0	0	0	0	0	gravel
37	0	0	76.9	6.4	0	16.7	0	0	0	0	0	gravel

Table D-26. Grain-size Results for Water screened Sediments from the Unit 1LSOLE, continued.

Phi	-5.5	-4.5	-3.5	-2.5	-1	-0.5	0	1.5	2.5	3.5	4.5	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04**	
Sample	**VCG$_1$**	**CG$_2$**	**MG$_3$**	**FG$_4$**	**VFG$_5$**	**VCS$_6$**	**CS$_7$**	**MS$_8$**	**FS$_9$**	**VFS$_{10}$**	**VCSilt$_{11}$**	**Textural Group**
45	0	0	46.5	13.5	0	40	0	0	0	0	0	sandy gravel
46	0	0	19.4	11.6	0	69	0	0	0	0	0	sandy gravel
47	0	0	55.8	9.9	0	34.3	0	0	0	0	0	sandy gravel
48	0	0	35	15	0	50	0	0	0	0	0	sandy gravel
49	0	0	59.7	9.3	0	31	0	0	0	0	0	sandy gravel
50	0	0	27.6	16.9	0	55.6	0	0	0	0	0	sandy gravel
50-1	0	0	62.3	14.1	0	23.6	0	0	0	0	0	sandy gravel
51	0	0	80.3	6.9	0	12.8	0	0	0	0	0	gravel

Table D-26. Grain-size Results for Water screened Sediments from the Unit 1LS2LW.

Phi	-5.5	-4.5	-3.5	-2.5	-1	-0.5	0	1.5	2.5	3.5	4.5	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04**	
Sample	**VCG$_1$**	**CG$_2$**	**MG$_3$**	**FG$_4$**	**VFG$_5$**	**VCS$_6$**	**CS$_7$**	**MS$_8$**	**FS$_9$**	**VFS$_{10}$**	**VCSilt$_{11}$**	**Textural Group**
27	0	0	42.3	20	0	37.7	0	0	0	0	0	sandy gravel
BBF3	0	0	79.4	5.2	0	15.4	0	0	0	0	0	gravel
28-11	0	0	69	7.8	0	23.2	0	0	0	0	0	sandy gravel
29-11	0	0	85.7	2.7	0	11.6	0	0	0	0	0	gravel
30-II	0	0	75.8	4	0	20.2	0	0	0	0	0	sandy gravel
31-11	0	0	49	9.3	0	41.7	0	0	0	0	0	sandy gravel
45	0	0	55.4	14.2	0	30.4	0	0	0	0	0	sandy gravel
46	0	0	49.8	14.5	0	35.7	0	0	0	0	0	sandy gravel

Table D-26. Grain-size Results for Water screened Sediments from the Unit 1LS2LW, continued.

Phi	**-5.5**	**-4.5**	**-3.5**	**-2.5**	**-1**	**-0.5**	**0**	**1.5**	**2.5**	**3.5**	**4.5**	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04**	
Sample	**VCG_1**	**CG_2**	**MG_3**	**FG_4**	**VFG_5**	**VCS_6**	**CS_7**	**MS_8**	**FS_9**	**VFS_{10}**	**$VCSilt_{11}$**	**Textural Group**
47	0	0	55.7	17.2	0	27.1	0	0	0	0	0	sandy gravel
48	0	0	55.4	14.2	0	30.4	0	0	0	0	0	sandy gravel
49	0	0	52.6	15.8	0	31.6	0	0	0	0	0	sandy gravel
50	0	0	42.8	14.8	0	42.4	0	0	0	0	0	sandy gravel
OF1	0	0	55.3	15.7	0	29	0	0	0	0	0	sandy gravel

Table D-26. Grain-size Results for Water screened Sediments from the Unit 1LS3LW.

Phi	**-5.5**	**-4.5**	**-3.5**	**-2.5**	**-1**	**-0.5**	**0**	**1.5**	**2.5**	**3.5**	**4.5**	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04**	
Sample	**VCG_1**	**CG_2**	**MG_3**	**FG_4**	**VFG_5**	**VCS_6**	**CS_7**	**MS_8**	**FS_9**	**VFS_{10}**	**$VCSilt_{11}$**	**Textural Group**
27	0	0	50.6	15.3	0	34.1	0	0	0	0	0	sandy gravel
BBF	0	0	60.2	12.2	0	27.1	0	0	0	0	0	sandy gravel
28-II	0	0	68.2	8.6	0	22.8	0	0	0	0	0	sandy gravel
30-II	0	0	52.6	18.1	0	29.3	0	0	0	0	0	sandy gravel
31-II	0	0	58.7	15.3	0	26	0	0	0	0	0	sandy gravel
45	0	0	65.9	11.8	0	22.3	0	0	0	0	0	sandy gravel
46	0	0	49.7	14	0	36.3	0	0	0	0	0	sandy gravel
47	0	0	50.6	17.4	0	32	0	0	0	0	0	sandy gravel
48	0	0	46.6	14.5	0	38.9	0	0	0	0	0	sandy gravel
49	0	0	63.1	9.2	0	27.7	0	0	0	0	0	sandy gravel
50	0	0	46.6	22.6	0	30.9	0	0	0	0	0	sandy gravel
51	0	0	25.8	18.7	0	55.5	0	0	0	0	0	sandy gravel

Table D-26. Grain-size Results for Water screened Sediments from the Unit 2LS1LE.

Phi	**-5.5**	**-4.5**	**-3.5**	**-2.5**	**-1**	**-0.5**	**0**	**1.5**	**2.5**	**3.5**	**4.5**	
Mm	**42**	**22**	**11**	**5.5**	**2.8**	**1.4**	**1**	**0.44**	**0.17**	**0.08**	**0.04**	
Sample	**VCG_1**	**CG_2**	**MG_3**	**FG_4**	**VFG_5**	**VCS_6**	**CS_7**	**MS_8**	**FS_9**	**VFS_{10}**	**$VCSilt_{11}$**	**Textural Group**
36	0	0	64.5	9.3	0	26.2	0	0	0	0	0	sandy gravel
37	0	0	54.3	14.6	0	31.1	0	0	0	0	0	sandy gravel
38-I	0	0	51.9	13	0	35.1	0	0	0	0	0	sandy gravel
40	0	0	44.3	14.4	0	41.7	0	0	0	0	0	sandy gravel
46	0	0	47	11.6	0	41.4	0	0	0	0	0	sandy gravel
49	0	0	46	15.4	0	38.6	0	0	0	0	0	sandy gravel
KE	0	0	64.5	2.2	0	3.3	0	0	0	0	0	gravel